JOURNAL

OF THE

FRANKLIN INSTITUTE

OF THE STATE OF PENNSYLVANIA,

FOR THE PROMOTION OF THE MECHANIC ARTS.

VOL. CXLIV DECEMBER, 1897 No. 6

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THE FRANKLIN INSTITUTE.

Stated meetings, September 15 and October 20, 1897.

MR. JOHN BIRKINBINE, President, in the chair.

THE SMOKE NUISANCE AND ITS REGULATION, WITH ESPECIAL REFERENCE TO THE CONDITION PREVAILING IN PHILADELPHIA—IMPROVED FURNACES AND MECHANICAL STOKERS.

VICARS' AUTOMATIC MECHANICAL STOKER.*

MR. WILLIAM H. THORNE:—The subject of the prevention of smoke from boiler furnaces has been so thoroughly discussed here, that it is unnecessary for me to do more than touch upon it.

The whole question of steam production presented itself to William Sellers & Co. years ago, not so much in regard to

* Manufactured by Wm. Sellers & Co., Incorporated, Philadelphia.

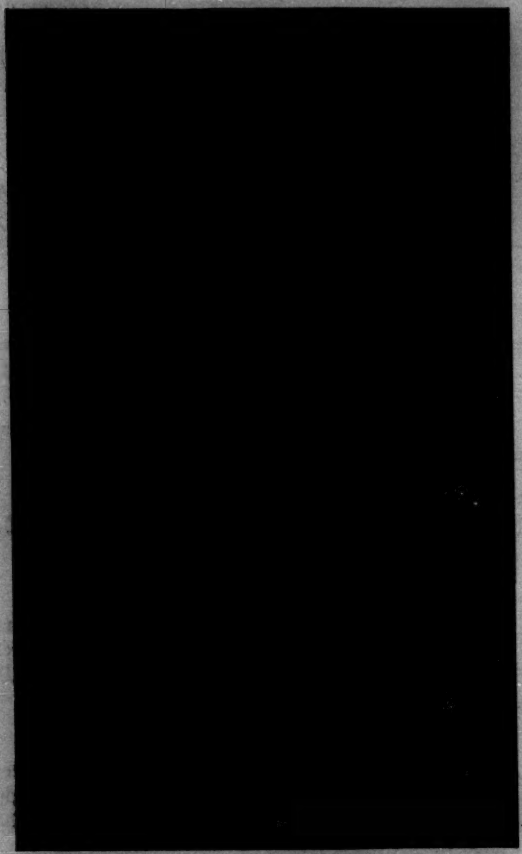


FIG. 1.—Battery of internally-fired boilers fitted with Vicars' automatic stokers.

the smoke nuisance, as in reference to the employment of cheap grades of coal, to the economical production of steam, to the orderly and systematic conduct of the boiler plant, and

to the bringing of that department of the works up to the standard of the others.

Recognizing that the English had been confronted with the same problem to a greater extent, and for a longer period of time, and under worse conditions, and that they were very

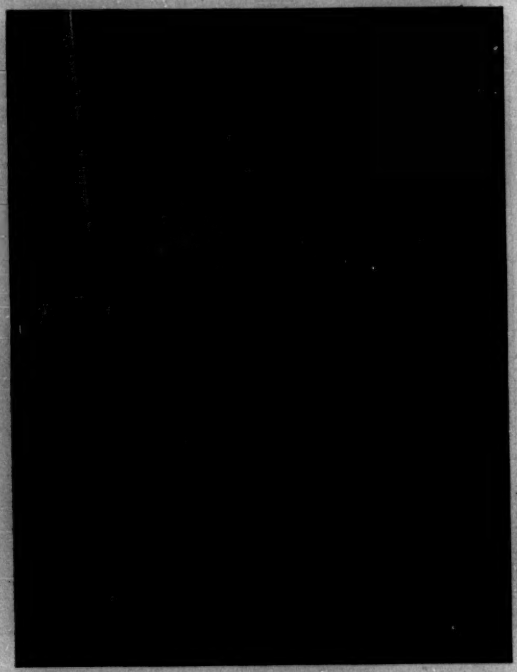


FIG. 2.

thorough in their investigations and persistent in their efforts to overcome difficulties, William Sellers & Co. made a study of what had been accomplished in England, with the idea of selecting the system best suited for use here.

The result was that one of Vicars' automatic stokers was purchased in England and installed in the Sellers' works in Philadelphia.

By its use, we were able to burn bituminous slack with perfect success and without any smoke, the boiler service was

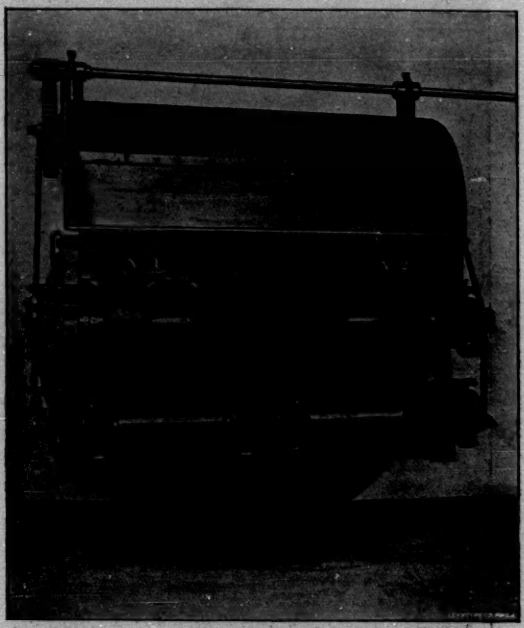


FIG. 3.

brought into order, a material economy was effected, and, the heat in the furnaces being maintained so constant and regular, the time lost in overhauling and repairs of the boiler was very much reduced—an entirely unexpected source of saving and safety.

The use of the stoker having proved so satisfactory, the exclusive right for its manufacture and sale in the United States was obtained. Various modifications to suit American requirements have since been made, and these requirements are characteristic and exacting. The so-called conservatism of the English induces them to work a long time in producing

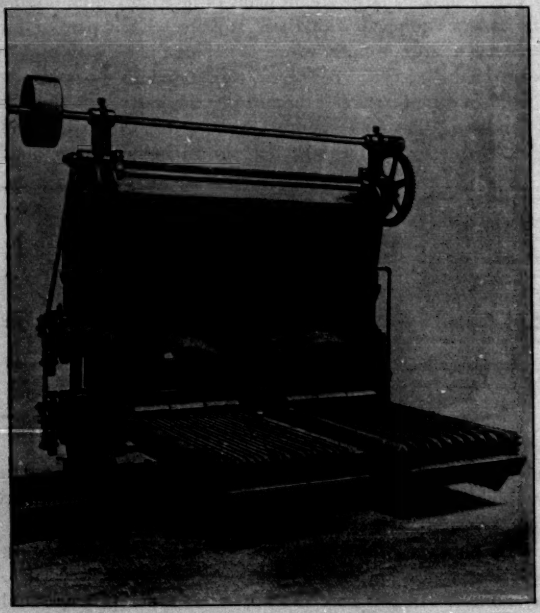


FIG. 4.

a good thing, but when its value is established, they adhere to it tenaciously. Consequently we find great uniformity in their types and proportions of boilers, which renders the problem of the application of stokers a comparatively simple one.

In this country the kinds and sizes of boilers are legion,

and the conditions so variable that each case must be carefully studied and the stoker rearranged and proportioned to suit.

I will now endeavor, by means of the illustrations, to explain construction and operation of the "Vicar's Stoker," and its application to different types of boilers.

Fig. 1 shows a large steam plant of internally-fired double-flue boilers equipped with these stokers. Each pair of furnaces has a large hopper, which is kept supplied with coal by means of the overhead conveyor, thus avoiding separate piles in front of each boiler and minimizing the labor, dirt and cost of handling. The coal is stored in the cellar, from which it is raised by means of the elevator, shown in the background,

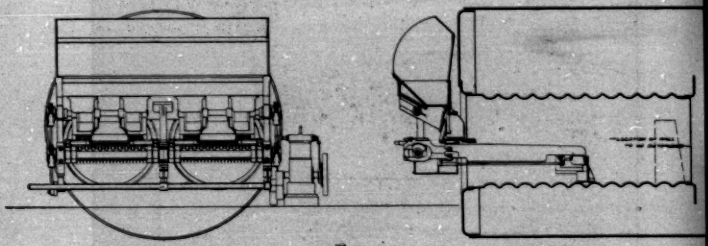


FIG. 5.

and distributed by an endless screw in a trough extending over all the hoppers. Various types of coal conveyors are used, depending upon local and financial conditions.

Fig. 2 is a view of the stoker that we imported from England, as it appears in use on one of our internally-fired Galloway boilers. In this case the hopper is kept filled by hand-shoveling, and, from our experience with it, we are convinced, contrary to the popular opinion, that the installation of a stoker on one boiler only is a profitable investment.

Fig. 3 is a front view of the stoker as built by us for internally-fired boilers, and, by means of it and the next view, I will endeavor to describe the details of the apparatus. In the bottom of the hopper are four openings into four inclined

chutes, one on each side of each furnace door. In each chute is a plunger, which can be slowly pushed down by means of a tooth on the horizontal shaft engaging with a tooth in the top

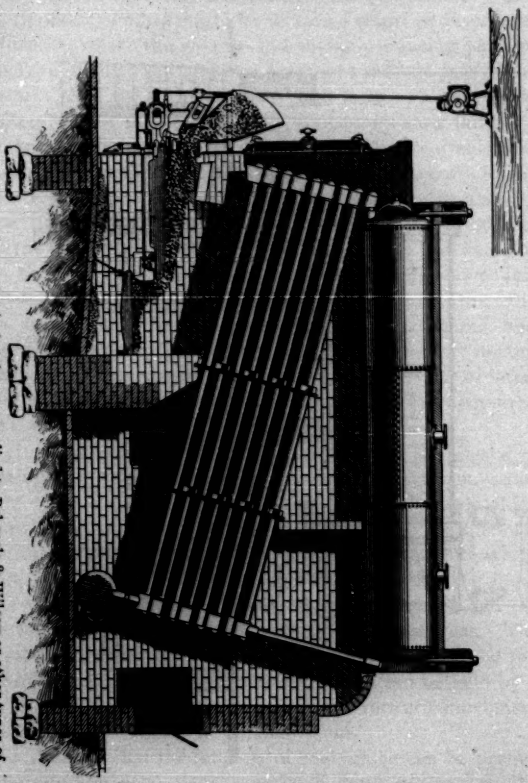


FIG. 6.—The Vicars' automatic mechanical stoker, as applied to Babcock & Wilcox or other types of externally fired boilers.

side of the plunger, and brought back when this same tooth engages with a tooth in the bottom side of the plunger. Each pair of plungers is operated by a separate shaft, and

when one plunger of each pair is going down its partner, is coming back. Each shaft has a ratchet wheel keyed on its end and a loose vibrating arm carrying a pawl. A cam can be set so as to permit the pawl to engage the ratchet teeth through

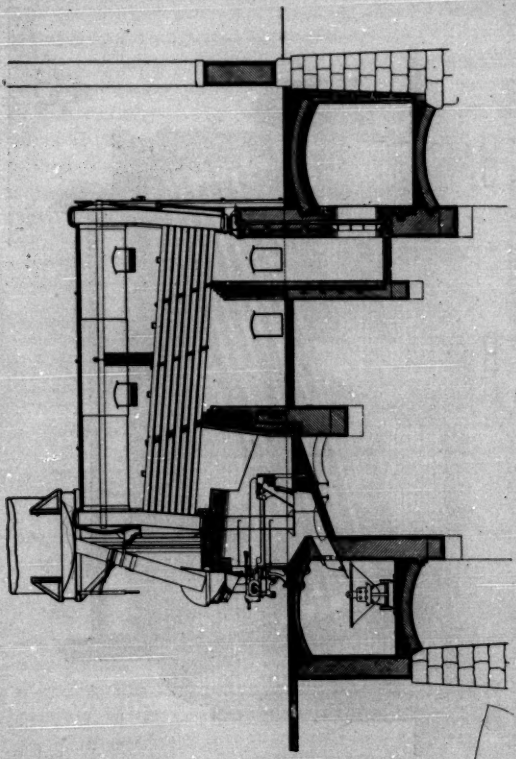


FIG. 7.

the entire vibration or any portion thereof down to zero. Thus, the plungers can be operated at any desired speed, or not at all, simply by adjusting these cams to notches pro-

vided for the purpose, and the amount of coal fed through each chute can be nicely regulated.

Fig. 4 is a rear view of the same stoker. The coal comes down the chutes on to the dead-plate, which is stationary, and forms the floor of what might be termed a retort or reverberatory furnace, where the volatile and smoke-producing parts of the fuel are distilled out and pass back into the hot part of the fire, where they are entirely burned and their own heat value is utilized. This coal is gradually pushed forward onto the grate bars. These grate bars have a peculiar, variable and perfectly governable motion. They all move forward into the furnace together, any amount required, from zero to about 4 inches. Then one alternate half of them remains at rest while the other half is drawn back. Then this half remains while the first half is drawn back. Then all move forward together again, and so the cycle goes on, the result being that the coal is slowly moved further and further into the furnace, while the ash, clinker and any unconsumed coal are discharged over the ends into the flues of internally-fired boilers, or upon a fixed grate of externally-fired boilers, where the combustion is completed.

Returning now to *Fig. 3*, we can examine the means of operating the grate bars. There is a vibrating arm, pawl, ratchet wheel and cam for determining the arc through which the pawl shall move the ratchet wheel, similar to the ones for operating the plungers. The shaft has four single teeth, which engage with single teeth in the four sliding frames, the inner two of which operate half of the alternate grate bars, and the outer two the other half, by means of two cross-trees. The inner sliding frames have no tooth on the top, while the top tooth of the outer ones is on a block, which can be held by a pawl in any position required to vary the forward movement of the bars from nothing to the maximum.

We thus see that the amount of coal which can be pushed down upon the dead-plate is variable, from nothing to the maximum, while at the same time the speed and distance that this coal can be moved forward through the furnace is variable, from nothing to the maximum, and that these regula-

tions are independent of each other and distinct for each furnace, so that any required condition of thickness of bed of fuel and of speed of traverse can be maintained with the utmost

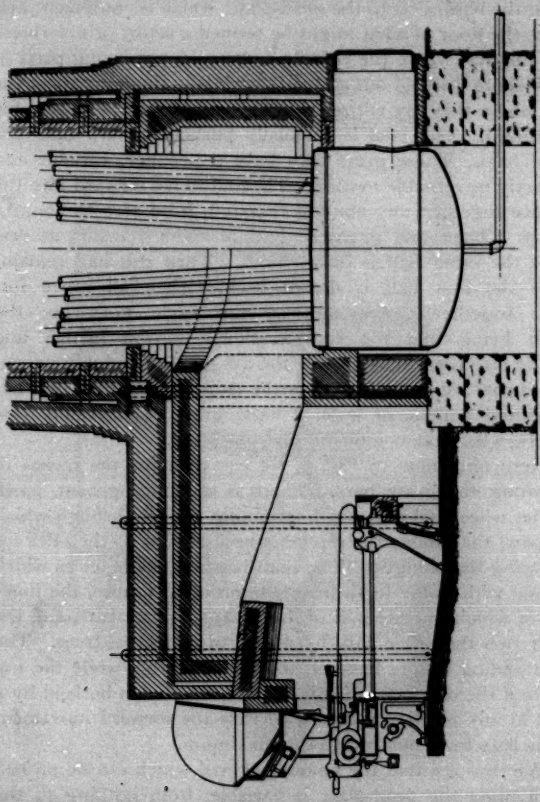


FIG. 8.

regularity, without inrushes of cold air or any disturbance of the fuel.

Between each chute is a full-sized fire door, which can be

let down flush with the dead-plate, and the furnace operated by hand and raked and sliced just as in ordinary hand practice. A readily opened peep door is placed directly over each fire door.

FIG. 9.

Fig. 5 is a sectional diagram of the stoker applied in corrugated flues.

Fig. 6 shows the stoker as applied to externally-fired boilers, with the fixed grate at the back, already referred to. The height and length of the fire-brick arch forming the retort for the fresh coal are varied to suit the kind of coal used.

Fig. 7 shows the stoker as applied in a large plant of externally-fired water-tube boilers, with the arrangement for handling the coal and ashes. The coal is dumped from the cars overhead into a tank over each hopper, and is let down, as required, by opening a slide in the pipe, while the ashes are raked down into the hand-car underneath.

Fig. 8 shows the stoker as applied to the external furnace of a vertical boiler.

Fig. 9 shows a number of photographic views of our foundry chimney-top taken at intervals of about two and one-half minutes when we were burning about 35 pounds of bituminous slack per square foot of grate per hour and developing over 200 horse-power. Nos. 1 to 10 show the results with the stoker working under the usual conditions, the only thing visible being the exhaust steam from the engine. Nos. 11 and 12 show the smoking possibilities of the fuel, the fires being then stirred and fuel added by hand, with the immediate and pronounced emission of smoke, as shown.

THE RONEY MECHANICAL STOKER.*

MR. WILLIAM R. RONEY [Baltimore, Md.]:—Mechanical stoking in this country has increased so rapidly during the last ten years, that it seems unnecessary to refer to the advantages which a good mechanical stoker possesses over any form of hand-fired furnace, for the smokeless and economical burning of bituminous coal. As an advocate of mechanical stoking, I was pleased to note that the gentlemen who took part in the discussion of the smoke nuisance at the April and May meetings of the Institute, almost unanimously recognized this fact.

This discussion has also emphasized another fact, viz.: that there is no mystery in smoke prevention. It is only a

* Manufactured by Westinghouse, Church, Kerr & Co., New York.

question of intelligent engineering. The problem of smoke or no smoke is simply that of *bad vs. good engineering*, and the recognition of four well-known requirements for complete or smokeless combustion. I referred to them in my remarks

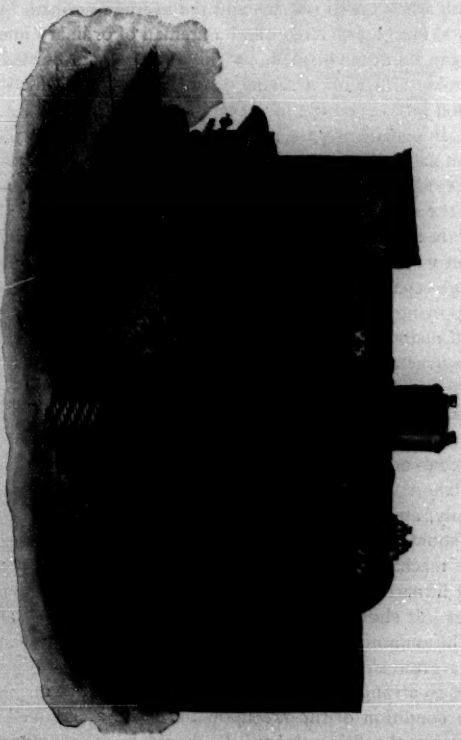


FIG 1.—The Roney mechanical stoker and smokeless furnace as applied to a horizontal return tubular boiler.

at the April meeting, and will venture to repeat. They are:

(1) Sufficient air to supply necessary oxygen.

(2) A thorough mingling of the oxygen with the volatile gases.

(3) A constant high temperature of air and gases.

(4) A uniform supply of fuel, regulated according to the demands for heat for steam making or other purposes.

To maintain all these conditions is practically impossible with a hand-fired furnace and the average fireman, but with a good mechanical stoker and a fireman of ordinary intelligence, it can be accomplished, and bituminous coal burned without smoke, and with a saving in fuel and labor which will pay good interest on the investment.

In considering the subject of mechanical stoking, the question naturally arises: How should a stoker be constructed, to meet all the varied conditions, or, in other words, what should be the characteristics of the ideal stoker? I would answer:

It should combine simplicity of construction and operation with efficiency, smokelessness, mechanical durability and large capacity, when necessary. It should work automatically, supplying the coal to the furnace as fast as may be required, and maintaining a uniform fire on the grate. It should be so constructed as to permit free passage through the grates of a large amount of air when required, and this should be accomplished without the aid of a slice bar. It should be so constructed as to make possible the easy application of a system of coal- and ash-handling machinery, for the further reduction of labor. It should discharge the ash and clinker quickly and easily, and without the admission of cold air to the furnace. It should be so constructed that the coal magazines and all the mechanism for feeding the coal shall be entirely outside the furnace, and where they will be unaffected by the intense heat. It should be capable of burning successfully all grades of bituminous, semi-bituminous, lignite and anthracite coals. The grate should be easily accessible from above and below, and so arranged that every part can be seen at all times, and the condition of the fire upon the grate ascertained without opening the firing doors. It should be so constructed that repairs can be reduced to a minimum, and worn-out parts be replaced without disturbing the remainder. It must be so simple as to be within the comprehension of the most ordinary mind, and yet, at the same time, in reality, compete with the

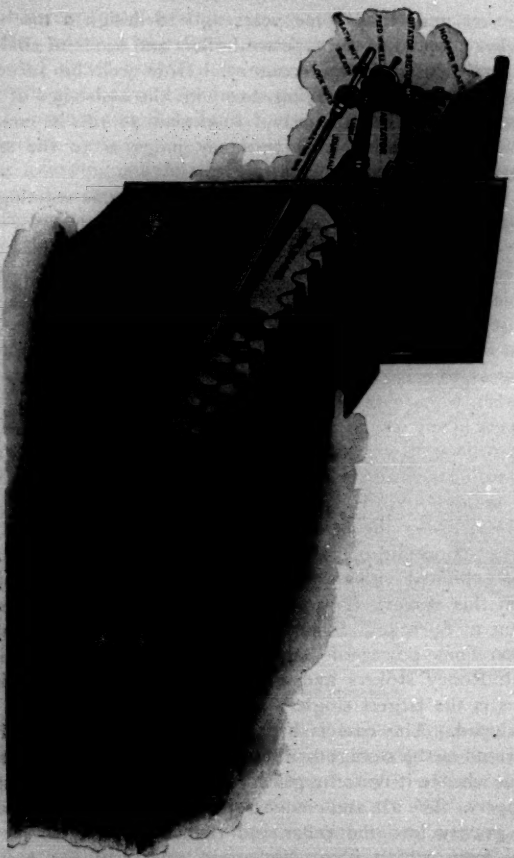


FIG. 2.—Sectional perspective of the Roney mechanical stoker.

work of a skilled hand-fireman, and do it with the accuracy of a machine, which will never "get tired" and never "strike."

It was with some such ideal stoker in mind, and with a conviction that this ideal had not yet been realized, that the

speaker undertook some years ago to design a mechanical stoker adapted to the types of boilers and kinds of coal most generally used in this country. How well he succeeded, modesty forbids my saying, but with the assistance of a few lantern slides, I will endeavor to explain to you its construction and operation, that you may judge as to the success attained.

According to the *Bulletin*, announcing this meeting, we, who address you, are expected to make "a statement of claims for efficiency." I feel that this is rather a difficult thing to do —not on account of any lack of efficiency in the apparatus which I have the privilege of describing to you to-night, as I trust will be evident, but on account of natural diffidence and a reluctance, which even stoker inventors may sometimes possess, to appear to "blow my own trumpet." Neither would I wish, when explaining the merits of my own apparatus, to appear in any way to detract from the merits of other mechanical stokers. I will, therefore, paraphrase a well-known remark regarding Kentucky's noted beverage by saying: "All stokers are good, but some stokers are better."

Mr. Roney then explained by means of lantern slides the construction and operation of the Roney Mechanical Stoker, and exhibited views of several large boiler plants equipped with this stoker. The most notable was that of the steam plant at Spreckels' Sugar Refinery, Philadelphia, containing 9,000 horse-power of Babcock & Wilcox boilers equipped with Roney stokers and coal- and ash-handling machinery. This is the largest single plant of boilers in the world thus equipped. The coal is brought by trainload, crushed and elevated to the storage bunkers at the top of the boiler house, from whence it flows by gravity through chutes to the stoker hoppers. The ash and cinder from all the boilers is discharged by gravity into the cellar and thence elevated to an ash-bin, from which it is discharged into cars for removal. So complete is the system, that from the time the coal is dumped into the crushers until the ash is delivered into the cars for removal no manual labor is required. The economy of labor and fuel is remarkable.

The last lantern slide shown was that of two steam pressure diagrams, taken at the Baltimore Electric Refining Works, before and after Roney stokers were installed, and illustrated vividly the great advantage of mechanical stoking over hand-firing in maintaining a uniform boiler pressure under sudden and extreme variations in the demand for steam.

The following is a detailed description of the construction and operation of this stoker:

"The Roney Mechanical Stoker and Smokeless Furnace" is shown in *Fig. 1* applied to a horizontal return tubular boiler,

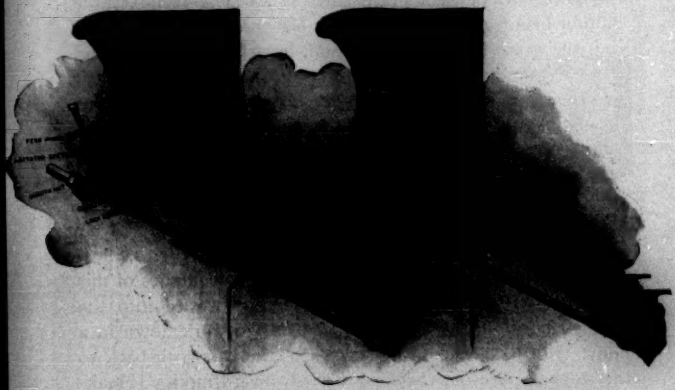


FIG. 3.—Details of feed and grate movement.

and *Figs. 2, 3* and *4* show the details of the latest construction, and the positions of the grate bars and feeding mechanism when in operation. From these illustrations it will be seen that it is a simple apparatus which receives the fuel in bulk, and without further handling, feeds it continuously and at any desired rate to the furnace; burns the combustible portion and deposits the ash and cinder in the ash-pit ready for removal.

In the bottom of the hopper is located a sliding pusher (see *Figs. 2* and *3*), actuated by a sector, which engages a rack on

the under side of the pusher, and by which it is given a reciprocatory motion, which gradually feeds the coal over the dead-plate and onto the grate. The grate consists of horizontal flat-surfaced bars, extending from side to side of the furnace, carried on side bearers, extending from the throat of the hopper to the rear of the ash-pit, and inclined at an angle of 27° from the horizontal. In the wider furnaces, two sets of grate bars are placed side by side, provided with independent actuating connections. The bars in each set are coupled together by a "rocker bar," the notches of which engage with a lug on the lower rib of each grate bar. A variable reciprocating motion being given to the rocker bar through a connecting rod, the grate bars rock in unison, now forming a series of steps and now approximating to an inclined plane, with their tops overlapping like the shingles on a roof (*Fig. 3*). The depending webs of the grate bars are perforated with longitudinal slots, so placed that the condition of the fire can be seen at all times and free access had to all parts of the grate without the opening of doors. These slots also serve an important purpose in furnishing an abundant supply of air for combustion. The sectional perspective cut, *Fig. 2*, illustrates clearly the form of the grate and the advantages of this construction. When the grate bars rock forward into the inclined position, the burning coal tends to work down in a body. But before it can move too far, the bars rock back to the stepped position, checking the downward motion, breaking up the bed of fuel and admitting a free volume of air through the fire. This alternate starting and checking motion keeps the fire constantly stirred and opened up from underneath, and finally lands the cinder and ash on the dumping grate, from which it is discharged into the ash-pit by releasing the dumping rod—the work of but half a minute. All this is accomplished without opening the fire doors.

The actuating mechanism is simple, all motion being taken from one driving shaft, extending across the boiler front and driven by a small engine. The power required has been found by test to be *less than one-quarter horse-power* for each 150 horse-power boiler. Motion is communicated to the

"agitator" by means of an eccentric or a crank and link, *Fig. 3*, and thence to the "agitator-sector" and rack. Through the eye of the agitator-sector passes a stud screwed into the agitator, on which stud is a feed-wheel, used to regulate the motion of the agitator-sector and pusher, the position of the feed-wheel on the stud determining the length of stroke of the pusher. The rocking of the grate bars is in like manner

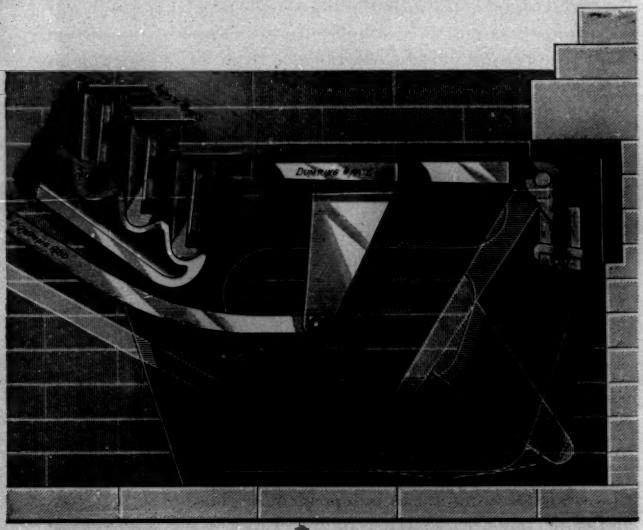


FIG. 4.—Details of dumping grate. The shaded outline shows position of grate when dropped.

regulated by the position of the "sheath-nut" and "lock-nuts" on the "connecting-rod." By these two simple adjustments, within the comprehension of the ordinary fireman, the whole action of the stoker is controlled, and the fires forced, checked or banked at will.

A coking arch of fire-brick is sprung across the furnace (see *Fig. 1*), covering the upper part of the grate, forming a

reverberatory furnace and gas-producer, whose action is to coke the fresh fuel and release its gases, which, mingling with heated air and steam supplied in small streams through the perforated tile above the dead-plate, are quickly burned in the large combustion chamber above the bed of incandescent coke on the lower part of the grate. This method of supplying the coal at the front and coolest portion of the furnace and gradually advancing it towards the hottest portion, presents conditions most favorable for complete and economical combustion, and in operation closely resembles a large Argand burner in the ease with which it is regulated and its smokeless combustion of the hydrocarbons of the coal.

This stoker burns successfully and smokelessly all kinds of bituminous, semi-bituminous, lignite and anthracite coals; the complete regulation of the feed and grate motion, together with the method just described, of supplying heated air and steam, adapting it to all the various coals used for steam making. Waste products, such as tan-bark, saw-dust, cotton-seed hulls and coke-dust are frequently burned in this stoker.

THE BABCOCK & WILCOX STOKER.*

THE SECRETARY:—"The Babcock & Wilcox Stoker," as shown by the accompanying cuts,† is an endless chain grate, mounted in frames carried on wheels, so that the stoker can be moved in or out without interfering with the brickwork.

The power for moving the grate and feeding the stoker thereon is furnished by an independent engine for each stoker, and is delivered by a ratchet and lever to a worm wheel. The coal is furnished either from a hopper overhead, or shoveled by hand in the ordinary way, and the coal feed is regulated by means of a gauge at the rear of the hopper, which can be raised or lowered according as a thick or thin fire is desired.

The grate consists of links, which can be readily removed should it become necessary to do so, and can be removed and

* Manufactured by the Babcock & Wilcox Company, New York.

† For the use of these illustrations the *Journal* is indebted to the *Transactions* Am. Society of Mechanical Engineers.

replaced in from ten to fifteen minutes; but experience has shown that it is seldom necessary.

The stoker is driven by the front sprockets, and is there-

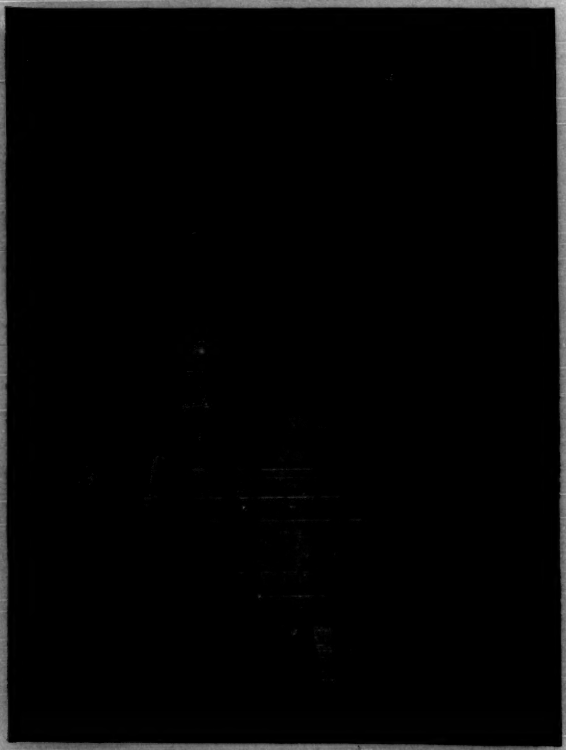


FIG. 1.—Babcock & Wilcox stoker removed from furnace.

fore pushed forward rather than pulled from the rear. There is a damper in the back, at the rear of the stoker carriage, for the purpose of preventing circulation of air between the stoker and the bridge wall.

When it is run in accordance with directions given by the manufacturer, the Babcock & Wilcox chain-grate stoker will give no more smoke from bituminous coal than a flat grate will give from anthracite coal.

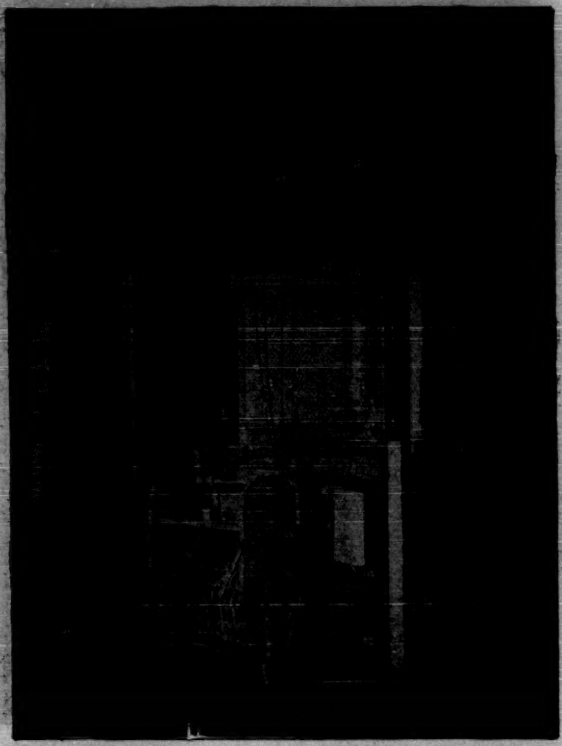


FIG. 2.—Front of Babcock & Wilcox chain-grate stoker.

As a labor-saving device, the stoker becomes valuable just as soon as the number of boilers in the plant require more than

one fireman. Its adoption in small plants, for the purpose of reducing labor, is not recommended.

Another advantage of the stoker is its ability to burn the

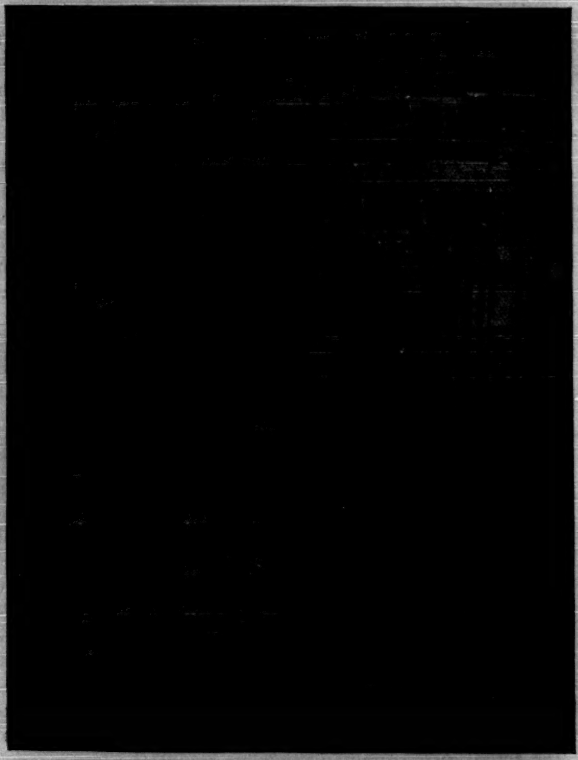


FIG. 3.—Driving mechanism of Babcock & Wilcox stoker.

low grades of fuel that cannot be burned on the ordinary grates. In places located a long distance from mines, where freight is a very large percentage of the cost of coal, this argu-

ment will not have much weight; but in places near the mines, where slack or low grades of fuel can be obtained at a small percentage of the cost of run-of-mine coal, the argument holds good, and the stoker will burn it as readily and with good economy.

The following conditions are important when using the Babcock & Wilcox chain grate:

Draft Conditions.—To get the best results from a mechanical stoker, a high rate of combustion must be maintained. This means that the draft must be good, and in all cases it will require not less than ¼ of an inch of water, measured in the furnace; and if the coal is of a very low calorific value, this pressure should be increased.

Fuel.—The chain-grate stoker, as designed by the Babcock & Wilcox Company, is adopted for burning bituminous coal *only*, and cannot be used with fuel that does not ignite freely.

The stoker is made in sizes ranging from 46 inches wide to 116 inches, length ranging from 6 to 8 feet. (From data supplied by the manufacturers and illustrated by a working model.)

THE AMERICAN STOKER.*

Mr. C. H. Bierbaum [Dayton, O.]:—From the previous discussions on the subject of smoke prevention, there seem to have been evolved these general concurrent ideas: that the proper way in which to effect an abatement of the present smoke nuisance is to burn the coal in such a manner that no smoke can occur; and that the great numbers of so-called smoke consumers with which the Patent Office has been flooded and the public beguiled are more or less an economic failure.

The greatest loss of heat existing in all ordinary furnace practice is that which is carried off by the chimney gases, and the actual losses due to incomplete combustion are so small, that only in cases of bad management do they become of sufficient consequence to deserve any consideration as regards

* Manufactured by the American Stoker Company, Dayton, O.

economy. The fallacy of the general notions that a clear stack signifies economy, and that a smoky stack means wastefulness, is being appreciated more and more. The principal loss from the incomplete combustion of gases is not indicated by the appearance of the chimney mouth, but is due to the escape of invisible gases, and the visible smoke formation is a rather insignificant item of loss. The experiments of Professor Tatlock, Scheurer-Kestner, and those made at Sibley College, all tend to show conclusively that the average heat losses due to the formation of smoke do not exceed three-quarters of 1 per cent.

Smoke proper is always the result of the incomplete combustion of hydrocarbons, whatever the fuels may be from

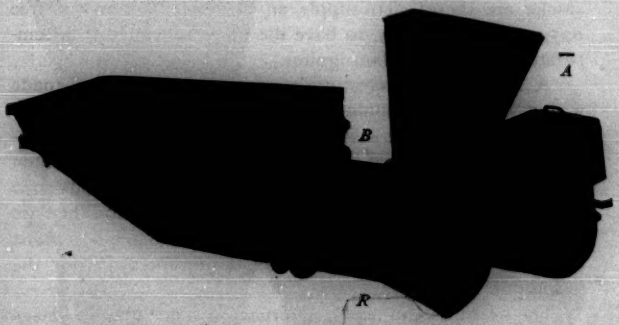


FIG. 1.—The American stoker.

which they have been distilled. Coke and charcoal, for example, burn without smoke, since in the process of manufacture they have already been deprived of their respective gaseous constituents.

The common kerosene lamp may be taken as the simplest smokeless furnace, designed specially for the burning of hydrocarbons—a furnace in which complete combustion occurs. The lamp, under proper conditions, burns with a bright, clear flame, free from smoke, with a large excess of the theoretical amount of air necessary for complete combustion.

Now remove the chimney and you have a smoky flame, notwithstanding the still freer supply of air. In fact, the smoke is due to an excessive admixture of cold air, operating to cool the body of the flame below the temperature necessary for the ignition of carbon. Now take a broken chimney with a small hole in the side at a point of its greatest diameter. If the hole be small enough, no appreciable effect may be apparent, but let a slight draft strike the chimney in a direction so as to enter the opening, and a smoky flame is the result. This is due to two conditions: A too limited supply of air from below, and the influx of air from the side, acting to cool the combustion chamber.

Thus, the two requisites for preventing the formation of smoke are these: To supply an adequate amount of free oxygen; and, secondly, to have the gases subjected to a temperature at which carbon ignites.

A number of interesting experiments have been made with a view of determining this temperature, and it is generally considered that it is somewhat above 3,200° F. The simplest experiment is that of taking an extremely fine platinum wire and thrusting it into the lower edge of the luminous zone of the flame, where the ignition of carbon begins, and the wire will be fused. The temperature of ignition of carbon must therefore be somewhat higher than the figure given for the fusion point of platinum, 3,227° F.

The heat losses in ordinary furnace practice may be classified under three heads: Radiation, incomplete combustion, and those due to an excessive dilution of furnace gases. The losses due to radiation are relatively small, and deserve but little more than due precaution. The entire losses due to incomplete combustion may be sub-divided into three classes: The loss due to the escape of an invisible combustible gas or gases, those due to the loss of the visible smoke, and the fuel loss in the ash. Those due to an excessive dilution are well illustrated by the operation of a plant with a moderately clean stack, to which the proprietor and neighborhood had ascribed good economy, and which showed, upon a careful investigation, that for a period of twelve hours an average of 35 per

cent. of the total heat generated in the furnace was carried off by the chimney gases, owing to an excessive use of air, which had largely been contributed by a patented air flue discharging at the bridge wall. In spite of this sacrifice in economy, the stack still, at times of firing, poured out large volumes of smoke.

An error that is commonly made is that of calculating the heat losses due to the escape of invisible combustible gases, as carbon monoxide (CO). This is a colorless gas, and has, *per se*, no relation with the visible smoke formation, notwithstanding that attempts have been made to compile tables

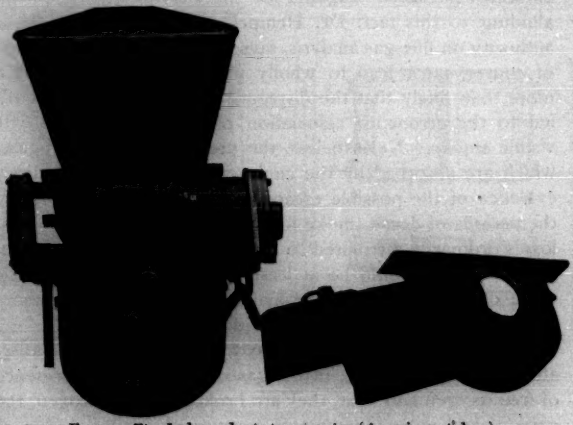


FIG. 2.—The Independent steam motor (American stoker).

giving the probable amounts of CO corresponding to certain densities of smoke. CO is always the product of dissociation, and its percentage is a direct function of the absolute temperature and pressure under which it was formed. That is, if we take a volume of carbon dioxide (CO_2), and subject it to a high temperature, the amount of carbon dioxide converted into carbon monoxide and free oxygen is a direct function of the absolute temperature and pressure. An increase of tem-

perature tends to increase, and an increase of pressure tends to decrease, the dissociation. It is quite unlikely that CO should ever be formed in our ordinary boiler furnace in any appreciable amount—even a trace of it is improbable when any free oxygen is present, and the temperature is above the ignition point of CO. In our flue gases we always find from 4 to 10 per cent. of free oxygen. One fact concerning this matter, which is often not taken into consideration, or perhaps not generally known, is this, that ethylene, acetylene and other hydrocarbons are quite readily absorbed by either the ammoniacal or the hydrochloric acid solutions of cuprous chloride, the usual reagents for the absorption of CO. In alluding to this fact, Dr. Hempel, probably the best living authority on flue-gas analysis, says: "The disregard of which, of course, must lead to wholly useless results." And it is more than likely that the disregard of the foregoing fact has led to the erroneous association of carbon monoxide with visible smoke. Nevertheless, the presence of a gas or gases which are absorbed by the cuprous chloride, gives us direct evidence of the possible escape of combustible gases during the periods of dense smoke formation, and therefore the heat losses ordinarily attributed to the existence of CO, and calculated as such, should be at least doubled, since the calorific value of a mixture of these hydrocarbons is probably more than twice that of carbon monoxide.

By the heat of the fire the hydrocarbons are either liberated or volatilized, and, in the gaseous state, in the presence of free oxygen and heat, they are broken up. Hydrogen, the gaseous and more inflammable constituent, ignites readily at a lower temperature than carbon. Now, if the combustion of the hydrogen does not produce a temperature sufficiently high for the ignition of the carbon also, the carbon then is permitted to pass off as soot. Take, for example, a single molecule of ethylene gas (C_2H_4). The 4 atoms of hydrogen combine with 2 of oxygen to form 2 molecules of water, and the 2 atoms of carbon remaining free are carried off suspended in the current of chimney gases. The reasons for the gases not always reaching the necessary temperature are quite

apparent: excessive dilution of the gases, a too rapid dissipation of heat by either radiation or conduction, and ofttimes by the presence of aqueous vapor in too large an amount. This vapor of water, or steam, never aids the combustion, and can only serve to produce a two-fold loss, in that it reduces the temperature below the ignition point of carbon; and, secondly, increases the volume and the aggregate specific heat of the gases, and thus augments the heat losses correspondingly. Cases are on record where steam jets are claimed to have produced phenomenal results. Any advantages from this cause can only have been of a mechanical nature, either by

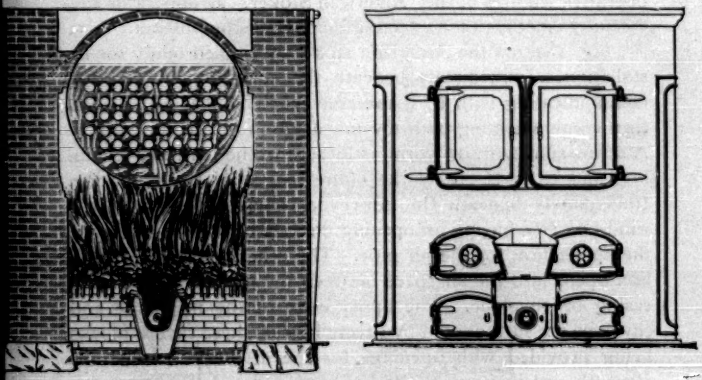


FIG. 3. Front view and cross-section (American stoker).

agitating the products of combustion where the combustion chamber was too small and no intermingling of the gases could otherwise be effected, or by its presence tending to precipitate the soot to the rear of the bridge wall, or somewhere in its course, and thus reducing the actual amount discharged by the stack.

The introduction of heated air above the fire for the purpose of perfecting the combustion can likewise never be made an entire success, since the temperature of this heated air must not only be equal to that of incandescent carbon, but

must greatly exceed it, in order that after mixing with the products of combustion a resulting temperature of this mixture shall be obtained sufficiently high to ignite the carbon. But since all our materials, suitable for the construction of air ducts sufficiently refractory to withstand this intense heat, are likewise extremely poor conductors of heat, a secondary furnace equal to or still larger than the original one would be required for heating the necessary air, thus simply transferring the problem of smoke prevention from the primary to the secondary furnace.

I will now invite your attention to the construction and operative features of the "American Stoker," an apparatus successfully employed for effecting smokeless combustion.

Fig. 1 shows the American stoker assembled ready for installation. Immediately beneath the coal hopper (*A*), and communicating with it, is the conveyor chamber (*B*), this in turn communicating with the magazine in direct line with it. A screw conveyor, or worm, is located in the conveyor chamber, and extends nearly the entire length of the magazine. Immediately beneath the conveyor chamber is located the wind-box (*R*), having an opening directly beneath the hopper, the connection for the air pipe. The other end of the wind-box opens into the air space between the magazine and outer casing or envelope. The upper edge of the magazine and envelope are surmounted by tuyere blocks, these tuyere blocks being provided with openings for the discharge of the air. Beneath and in front of the hopper is located the motor for operating the stoker.

Furnaces over 6 feet in width, and too wide for a single stoker, are equipped with the double stoker. This is a combination of two single machines feeding from a common hopper and operated by the same motor. The space on each side of the stoker, between the tuyere blocks and the side walls of the furnace, is occupied by dead-plates, or air-tight grates. The incombustible portion of the coal congeals into a vitrous clinker, accumulating on these dead-grates in lumps quite free from coke. In a twelve-hour test by Prof. W. B. Potter on a battery of six double stokers at the Anheuser-Busch Brewing

Association, St. Louis, it was found that only .93 of 1 per cent. of fixed carbon had been lost in the ash.

Fig. 2.—The motors are simply piston steam engines. The piston rod carries a cross-head, which, by means of suitable connecting links, operates a pawl mechanism, which, in turn, actuates the ratchet wheel mounted on the conveyor shaft.

Fig. 3 shows a general front view and cross-section of a boiler furnace equipped with the American stoker. *Fig. 4* is a longitudinal sectional view of the stoker beneath a tubular boiler.

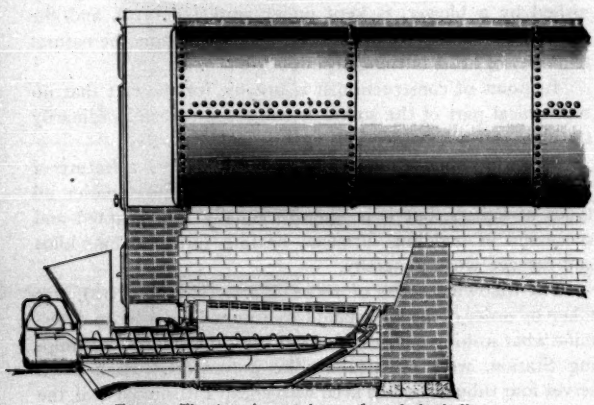


FIG. 4.—The American stoker under tubular boiler.

The coal is fed into the hopper, carried along by the conveyor through the magazine, overflows from it on both sides, and spreads upon the dead-plates the entire width of the furnace. The entire mass of coal above the tuyere blocks, and all of that upon the dead-plates, is ignited, carrying a bed of burning coke from 14 to 18 inches in depth.

The two prerequisites for combining smoke prevention with economy are: A complete combustion of the hydrocarbons, and using the least possible amount of air. It is

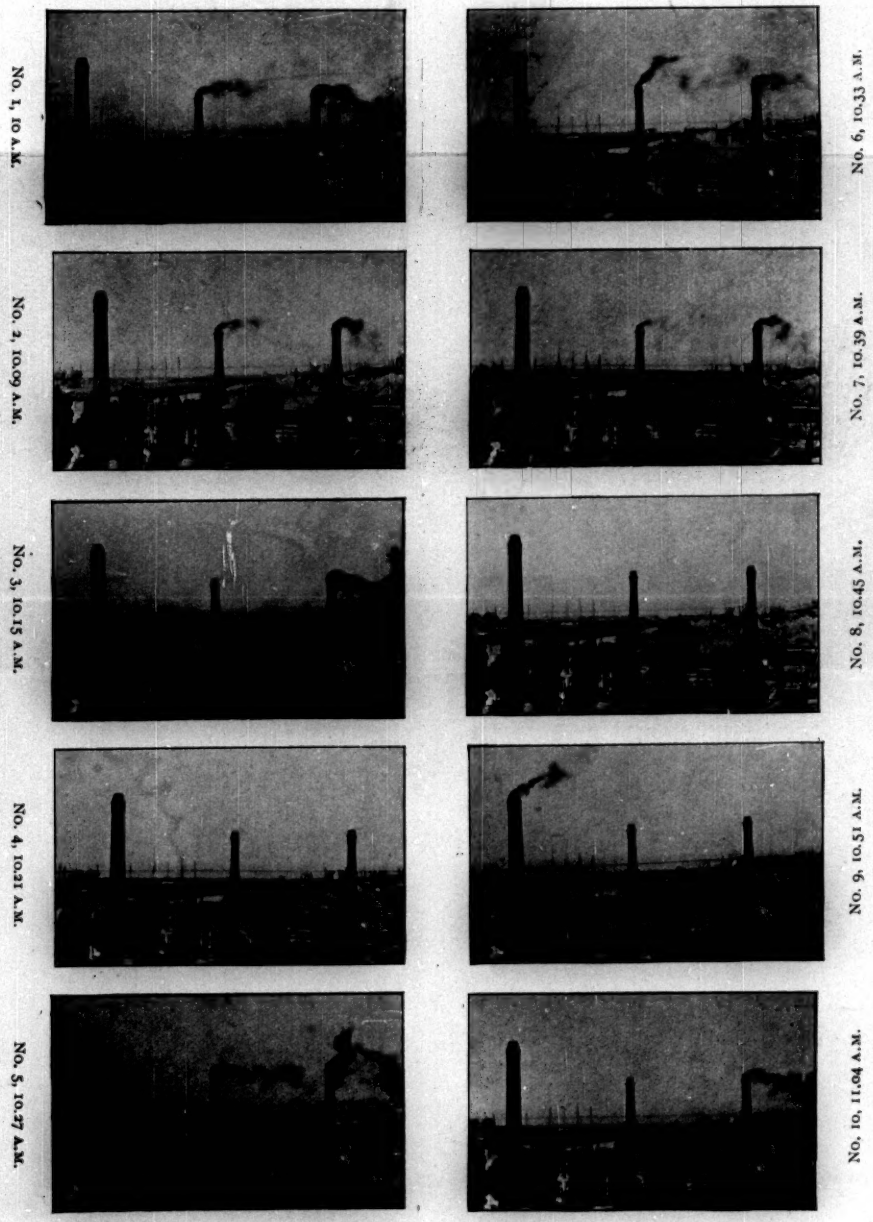


FIG. 5. Stack to left, American Stoker.

quite evident that none of the gaseous constituents of the coal can escape perfect combustion under the proper conditions of operation of this stoker. The green coal, being fed from underneath the bed of fire, liberates its hydrocarbons upon coming in contact with the fire. The air, being supplied at this point where the hydrocarbons are evolved, is mixed with them, and this mixture then, in turn, passes through the deep bed of incandescent coal. The economic use of air is due to the method of operation also peculiar to this stoker, in that it carries a bed of coal of unusual depth, the air being supplied from underneath, the volume of which, being furnished by a blower, is kept under perfect control, and the continuous upward feeding of the coal counteracts the natural tendency of holes burning through the fire.

In point of construction it is notable for the fact that no mechanical part of the stoker is subjected to heat, ordinarily the chief cause for objections against stokers.

The wide application of this stoker is no less a feature of interest. Not only has it been successfully used under all types of boilers, but it is likewise equally well adapted and successful in puddling furnaces, heating furnaces, lime-kilns and furnace work generally.

The following series of views, *Fig.* 5 (Nos. 1 to 10), was taken by order of the Cleveland City Council, in order to determine what stoking devices, in use at the Division Street Pumping Station, were practical smoke preventers. Each stack serves four tubular boilers fired with cheap Pittsburgh coal, the three sets of boilers doing the same amount of work. The stack to the left in each view represents the American stoker.

THE WILKINSON AUTOMATIC STOKER.

Mr. Wilkinson [Bridgeport, Pa.]:—In calling your attention to the "Wilkinson Mechanical Stoker," it behooves me to say, first, that in its main features of mechanical construction and performance, it differs very little from other forms of stokers; that is, it is provided with a hopper to receive

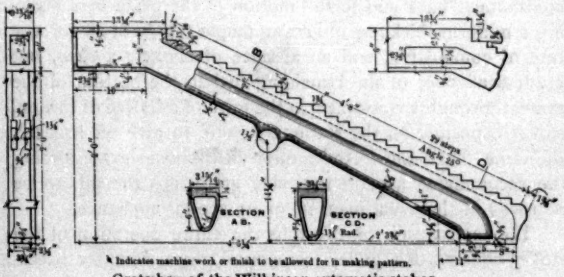
* Manufactured by the Wilkinson Manufacturing Company, Bridgeport, Montgomery County, Pa.

the coal, a grate on which to burn the coal. In its system of burning fuel, however, it is not at all like others.

As a device for burning of the cheaper grades of anthracite or bituminous coal, it is particularly efficient.

Having reference to the illustrations,* it will be observed that all that portion of the boiler front below the bottom line of boiler, together with the grate bars, bearer bars, etc., as in ordinary practice, is eliminated from first cost when new installation is considered, or discarded when it is proposed to add the stoker to a boiler in use.

In place of these a stoker front, suited to the purpose, is furnished; and at either side of the furnace, heavy side frames



Grate-box of the Wilkinson automatic stoker.

are placed, extending diagonally the whole length of the grate, tying the stoker front securely to the bearer bar or blast box at the back. Suitable projections on the stoker front support the mechanism for moving the grate bars, and admit of securing the coal hopper and blast pipe, as shown.

The grate bars are a series of hollow castings approximately of rectangular cross-section, placed side by side, and inclined toward the bottom of furnace, at an angle suited to the repose of the fuel; the upper end (open to admit the blast pipe) projects through and is supported by the stoker front, the lower end sliding on and supported by the bearer bars, as

* For the use of these cuts the *Journal* is indebted to the *Trans.* Am. Society of Mechanical Engineers.

shown. Throughout the inclined length and on the face of each bar is cast a succession of steps, solid on the tread, but through the rise of each step a vent of ample proportion is provided to inject air through the fire to the combustion chamber.

The grate bars are independently connected to the moving mechanism, and by this means an alternate "back and forth" motion is given to the whole series that is constant and uniform.

A pusher, shown resting on the top of the grate bars, is doweled to each alternate bar, and advances and recedes with them, pushing the coal on to the front end of the grate; the continuous "back and forth" motion of the grate bars insuring a uniform thickness of fire; an ample supply of air for any rate of combustion, and an absence of clinker; a slow, but gradual advance of the remaining fuel to the bottom of the grate, thoroughly consumed, in the form of ash, free of carbon, and is deposited on the stationary grate to give off its heat, the same "back and forth" motion of the main grate forcing the accumulated ash off the table grate into the pit, to be removed in the usual manner, or by special appliances.

The mechanism for effecting the entire operation of the stoker consists of a pulley, compound gears, with the necessary levers and shafts. The power required does not exceed one-tenth of 1 horse-power for each stoker.

The blast is saturated steam through nozzles of one-sixteenth of an inch opening, giving an induced current of air of wide range and under complete control of the attendant.

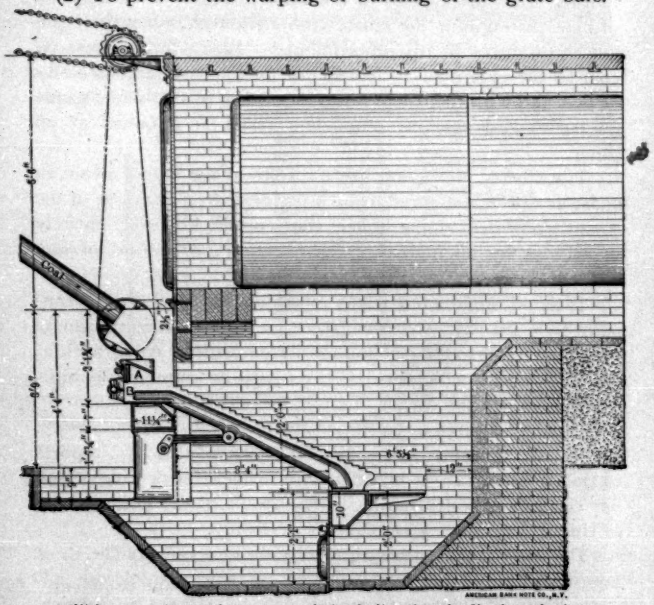
The special features incorporated in this particular stoker are as follows:

(1) The subdivision of the air blast, *i. e.*, every 4 inches of furnace width, which is the width of each grate bar, has twenty-seven tuyere openings, 2½ inches by ⅝ inch, about 1½ square inches area; a furnace 60 inches wide will contain fifteen bars, hence $15 \times 27 = 405$ miniature blacksmiths' fires, equally divided over the fire bed; aside from this every 4 inches of furnace width is as an independent furnace, having its own mechanism and its own steam jet.

The use of this steam jet has a three-fold purpose:

(1) To induce the air in measured quantities at the will of the attendant, thereby regulating the rate of combustion and consequently the production of steam in quantities desired from minimum to maximum by simply turning the regulating valve.

(2) To prevent the warping or burning of the grate bars.



Wilkinson stoker under return-tubular boiler (longitudinal section).

As an example of the efficiency of this, I have only to say that the first stoker of this design was installed under a return tubular boiler in the Rebecca Paper Mill, at Bridgeport, Montgomery County, Pa., in December, 1891, and that the same identical grate bars are still in operation, apparently as

good as when new, after six years' continuous use of twenty-four hours per day, equaling about twelve years' actual service of ten hours per day.

(3) The steam used in this device being pent up in an enclosed bar, and finding no other outlet but through an incandescent body of fire on the grate, becomes dissociated, and, uniting with the carbon of the fuel, produces a distribution of heat throughout the entire combustion chamber that cannot be produced in any other manner. Flame from anthracite coal to the extent of 40 feet is not an impossibility with this device, and with the use of bituminous coal of the lowest grade an entire and absolute smokeless result is obtained at all times.

The cost of producing these results in the use of steam is, as far as can be measured, from 5 per cent. to 7 per cent. of the steam generated in the boiler; that cost is, however, entirely wiped out by an increasing evaporation per pound of fuel burned.

Carefully conducted trials, in which the Wilkinson Company took no part whatever, show as high an evaporation as 12·9 pounds of water per pound of combustible, using anthracite buckwheat, which evidences as high an economy as hitherto known by any means.

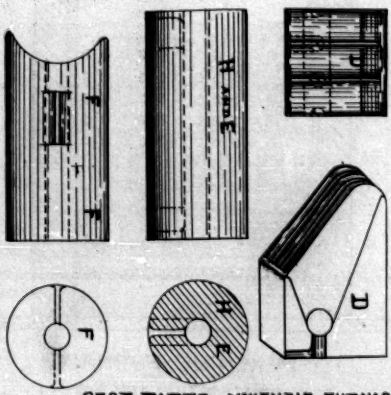
Capacity figures as an important factor also in this device. Mr. Jay M. Whitman, an expert engineer, of this city, reports to this company a test made by him in New York City of 126 per cent. over boiler rating, as the result of the performance of this stoker, with a satisfactory economy.

This stoker can be seen in operation in several of the most important industrial establishments in this city, whose addresses the Wilkinson Company will be pleased to furnish, and also at the works of the Wilkinson Company, at Bridgeport, Montgomery County, at any hour of the day, burning bituminous gas coal slack, *absolutely without smoke.*

THE McKENZIE SMOKELESS FURNACE.*

THE SECRETARY:—The McKenzie furnace is constructed on the well-known principle that air, properly admitted to the furnace and mixed with the gases, will give perfect combustion, preventing the formation of smoke, and at the same time giving the best efficiency from the fuel.

The secret of economy in the burning of fuel is perfect combustion. A smokeless furnace to be of practical use, must be adapted to all types of boilers; and it must have durability with simplicity of construction, which reduces the cost of repairs to a minimum.



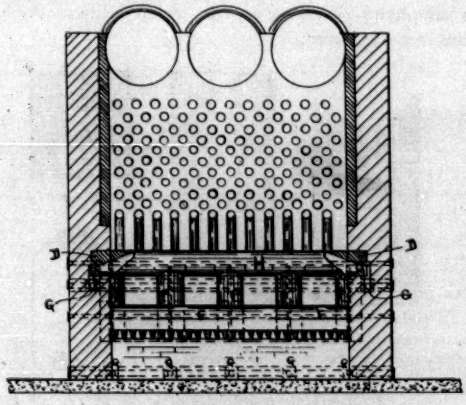
SECT. PARTS McKENZIE FURNACE

The McKenzie furnace is designed to meet these requirements, as the following description of the furnace will show:

The furnace is made of heavy, refractory fire-brick material, especially burnt for us to withstand the strain of expansion and contraction caused by intense heat. We find the life of the material to be from two to five years, according to the work done. The side deflectors marked *D*, which are directly exposed to the flames, weigh 160 pounds each; the air columns

* Manufactured by the McKenzie Furnace Company, Chicago, Ill.

marked *F*, weigh 375 pounds each; the cross distributors *H* and *E* also weigh 375 pounds each, making all the shapes exposed to the greatest heat substantial and durable. The deflectors *D* are built directly in the side walls of the furnace and overhang the grates, as shown in the cross-section, and are so designed that the back of the shape is heavier than the projecting nose, making it self-supporting in the wall, although the wall rests on it.



McKENZIE FURNACE
SECTION THRO FIRE BOX
WATER TUBE BOILER

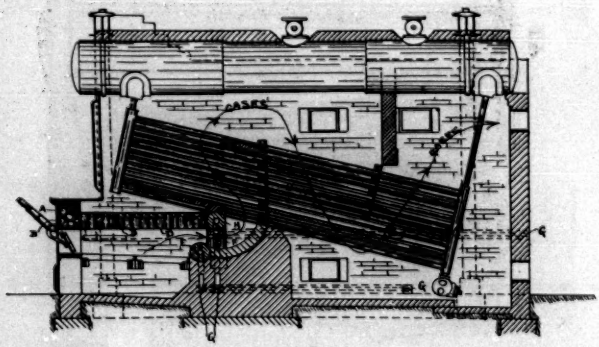
The columns marked *F* are set in the bridge wall 18 inches apart, across the setting, and support the heavy cross distributor marked *H*, both being 14 inches in diameter and very strong. The other cross distributor marked *E*, is cemented on the top of the bridge wall near the end of the grate bars, as shown in the longitudinal section.

All the air distributors and vital parts are thoroughly protected from the firing tools.

The retort marked *A*, resting on the door liners, is made of

cast-iron, protected from the fire by a fire-brick wall, the distributor marked *C*, is set in the retort 6 inches apart, and air, passing through the exposed lips, prevents them from fusing.

The door liners are made very heavy (1½ inches thick) to withstand the heat. The grates and fronts are the same in most cases as on ordinary furnaces; any grate can be used in connection with the furnace. The door is a lever-adjustable one, hanging on a hinge on either side of the liner and lifted by a finger in the center of door moved by the lever and ratchet, reducing the time of the door opening to a minimum, preventing the admission of cold air.



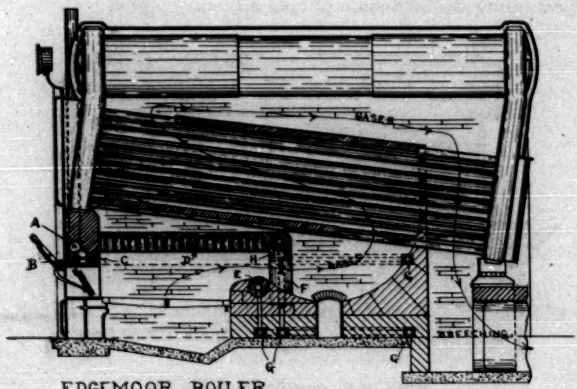
BABCOCK AND WILCOX BOILER
EQUIPPED WITH
McKENZIE FURNACE

The cost of repairing the furnace is very small, as the shapes are durable, can be reset by any handy man or mason about the plant, and are all interchangeable. In addition to this, it is never necessary to shut down the boiler to repair the furnace, as a damaged part will not materially affect its working, and can be repaired when it is convenient to shut down—a point very important where the boilers are pushed to their capacity and cannot be spared.

The operation of the furnace is the same as that of any hand-fired furnace; the air chambers requiring little or no

attention, the opening at the side of the setting to the chambers marked *G*, being closed by a sliding iron door, which is opened to a fixed point regulated by the grade of coal used. On the cheapest grade of slack the doors are wide open, while with the best grade of coal the doors would be about one-third open. This point of opening is fixed by us, and regulated by the fuel used by the furnace, and, as the grade of coal used is generally the same from month to month, the air doors require no attention.

As the furnace becomes heated, the air rushes in through



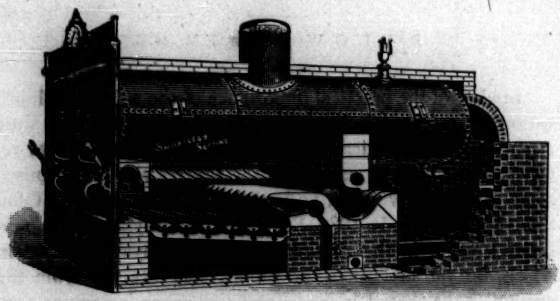
EDGEMOOR BOILER
fitted with
McKENZIE FURNACE.

the chamber, marked *G*, to the fire-box, through the long thin slots in the shapes, and is mixed with the gases at all points above the fuel, supplying sufficient oxygen for good combustion and preventing smoke. The retort, maked *A B C*, over the doors in front, also supplies air, and can be operated in two ways, either by admitting air at atmospheric pressure, or by admitting steam through the high-pressure retort, marked *B*, the steam passing through an opening $\frac{3}{64}$ inch in diameter through a nipple, forming a partial vacuum in the distributer, marked *C*, and forcing a larger quantity of air into the furnace.

In ordinary cases, the high-pressure retort is not used, and the air is admitted in much the same manner as through the other retorts.

The high-pressure retort is used only when it is necessary to force the boiler for capacity, and over 100 per cent. over-rating has been obtained on water-tube boilers when using this retort.

The steam taken by the high-pressure retort is less than 1 per cent. of the evaporation, and this is not considered a waste, as it pays for itself in the extra work done. All the air admitted goes into the furnace under atmospheric pressure, and is made to pass through the entire length of the setting



McKenzie furnace attached to return tubular boiler.

in nearly all cases. This heats the air before it comes in contact with the gases and overcomes the bad effects of cold air.

We claim for the furnace the following meritorious points, all of which have been amply demonstrated in its practical service:

(1) The prevention of all objectionable smoke by the better combustion obtained. (2) Greater efficiency from the greater percentage of the calorific power obtained from the fuel. (3) More water evaporated per pound of coal from the better combustion. (4) Less coal consumption per horse-power per hour from better combustion. (5) Adaptability to

all types of boilers. (6) Moderate first cost, durability and ease of repairing. (7) Adaptability to plants where the quantity of steam used varies, and where there is necessity of getting steam very quickly, as in electric light plants; this is attained by the easier firing and the better and quicker combustion obtained. (From data furnished by the manufacturers.)

[*To be Continued.*]

On the Theory of Lubrication and the Determination of the Thickness of the Film of Oil in Journal Bearings.

By F. L. O. Wadsworth, E.M., M.E.

In view of the practical importance of the subject of lubrication to mechanical engineers, it is surprising how little attention the theoretical consideration of the subject has received. The writer's interest in the subject was first aroused some years ago, while an undergraduate student at the Ohio State University. In 1886, Prof. Osborne Reynolds had published a paper in the *Transactions* of the Royal Society,* in which, for the first time, the subject was attacked from the ground of the theory of fluids, and some very important conclusions deduced and compared with the results of experiment. As these results do not seem to be as generally well known as their importance deserves, it may be well to first of all briefly review Professor Reynolds' paper. In doing so, I shall, in many cases, quote directly from the paper itself, because the author has stated his conclusions in so clear and concise a manner, that it would be impossible to condense or abbreviate his statements without losing some essential point.

* "On the Theory of Lubrication and its Application to Mr. Beauchamp Tower's Experiments, including an Experimental Determination of the Viscosity of Olive Oil," by Professor Osborne Reynolds. *Transactions* Royal Society of London, Vol. 177, pp. 159-234, 1886.

The hydronamical equation for the flow of a viscous fluid, such as oil, in thin sheets, was simultaneously derived by Professor Reynolds and Lord Rayleigh and Professor Stokes.* It is

$$\frac{d\,p}{d\,x} = \frac{6\,\mu\,V(h - h_1)}{h^3} \qquad (1)$$

where p is the intensity of pressure; V the velocity of motion of one side of the sheet with respect to the other, in the direction x; h, the distance between the shaft and the journal box (*i. e.*, the thickness of the oil film); h_1 being the value of h, for which p is a maximum; and μ the coefficient of viscosity. In the case of a journal revolving in its box, the equation is transformed as follows:

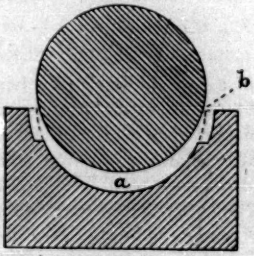


FIG. 1.

Let R (*Fig. 1*) be the radius of the shaft; $R + a$† that of the box. Let the center of the journal be at J, and that of the journal box at I, and let $J\,O$ be the line of load cutting the journal box symmetrically at L. Then if P denote any point x at the surface of the journal at which the pressure is p and the thickness of the film h; P_1 the point of greatest pressure, corresponding to the thickness h_1, and H the point of minimum thickness of the film; and if we put

*See report of the meeting of the British Association for the Advancement of Science, Montreal, 1884.

† In the figure, a is greatly exaggerated to avoid confusion.

$$< O J P = \theta$$

$$< O J G = \frac{\pi}{2} - \phi_0$$

$$< O J P_1 = \phi_1$$

$$J I = c\,a$$

where c is a proper fraction,
we have directly (neglecting quantities of the order

$$\left(\frac{c\,a}{R}\right)^2$$

$$d\,x = R\,d\,\theta$$

$$h = a\,[1 + c\,sin\,(\theta - \phi_0)]$$

$$h_1 = a\,[1 + c\,sin\,(\phi_1 - \phi_0)]$$

and substituting these values in (1) we get

$$\frac{d\,p}{d\,\theta} = \frac{6\,R\,\mu\,V\,c\,[sin\,(\theta - \varphi_0) - sin\,(\varphi_1 - \varphi_0)]}{a^2\,[1 + c\,sin\,(\theta - \varphi_0)]^3} \qquad (2)$$

In the case of a journal freely revolving in its box and separated from it by a film of oil of thickness h, there is a condition of equilibrium when the resultant of the pressure p, plus the frictional resistance to motion, f, is equal to the external load L and opposed to it in direction; *i. e.*, acts along the line $J\,O$. When there is no longitudinal pressure in the bearing the only remaining unbalanced force is one tending to rotate the journal box. Let M denote the moment of this force per unit length of the shaft. Then we have the additional equations:

For resultant of forces along $O\,J$

$$= L = \int_{-\theta_1}^{+\theta_1} (p\,cos\,\theta + f\,sin\,\theta)\,R\,d\,\theta \qquad (3)$$

For resultant of forces at right angles to $O\,J$

$$= O = \int_{-\theta_1}^{+\theta_1} (p\,sin\,\theta - f\,cos\,\theta)\,R\,d\,\theta \qquad (4)$$

For turning moment on box

$$= M = R \int_{-\theta_1}^{+\theta_1} f\,R\,d\,\theta \qquad (5)$$

$2\theta_1$ being the extreme angle $C\ I\ D$ (bisected by the line $J\ O$), subtended by the journal box.

At the edges of the box the pressure $p = p_0$, the external pressure of the film, usually simply that of the atmosphere.

For the frictional resistance between two parallel plane surfaces moving with a relative velocity, V, and separated by a film of viscous fluid of thickness, a, we have

$$f = \mu \frac{V}{a}^* \tag{6}$$

In the case of a cylindrical bearing and a film of variable thickness h, this expression becomes

$$f = \frac{3\ \mu\ V\ c\ [\sin(\theta - \varphi_0) - \sin(\phi_1 - \phi_0)]}{a\ [1 + c\ \sin(\theta - \phi_0)]^2} - \frac{\mu\ V}{1 + c\ \sin(\theta - \phi_0)} \tag{7}$$

$$K_1 = \frac{6\ R\ \mu\ V}{a^2}$$

These equations can be integrated directly for very small values of c, and were integrated by methods of approximation (of which it is unnecessary to give details here) for various values of c, up to $c = 0{:}5$, beyond which point the particular methods of approximation adopted can no longer be applied.

From these results Professor Reynolds has computed the following table, giving the pressure round the bearing at intervals of 10°, and also at particular points, $\theta = \pm\ 29°\ 20'\ 20''$, two points at which the pressure was experimentally measured in certain experiments of Mr. Tower, with which the results of theory are subsequently compared; $\theta = \pm\ 78°\ 31'\ 20''$, the extreme edges of the boxes; $\theta = -\ 7°\ 21'\ 40''$, the point of maximum pressure P_1; and $\theta = -\ 76°\ 38'\ 20''$, the point of minimum pressure.

* This supposes that there is no slipping at the boundary between the fluid and the surfaces in contact with it. That there is no such slipping (at least when the film is thin) has been established by the experiments of Poiseuilles (Paris: Mem. Savants Etrang., Tome 9, p. 434, 1846), and of Reynolds (Phil. Trans., Vol. 174, p. 935, 1883).

θ (on side)*	$\frac{p - p_0}{K_1 c}$	θ (off side)*	$\frac{p - p_0}{K_1 c}$
78° 31′ 20″	·0002	0° 0′ 0″	1·0151
70°	·1002	−7° 21′ 40″	1·0269
60°	·2249	−10°	1·0232
50°	·3555	−20°	·9412
40°	·5·03	−29° 20′ 20″	·7923
29° 20′ 20″	·6609	−40°	·5612
20°	·8022	−50°	·3349
10°	·9331	−60°	·1449
0°	1·0151	−70°	·0293
		−76° 38′ 20″	−·001
		−78° 31′ 20″	·0002

$$K_1 \frac{6 R \mu V}{a^2}$$

Since the value of $p - p_0$ varies directly as R and V and inversely as a^2, it follows that since the latter quantity is very small, while the two former may be very large, the pressure in the film of oil may sometimes rise to a very high figure. In one case, indeed, the difference, $p - p_0$, was found by actual measurement to be over 600 pounds per square inch. And it is the very fact of this excess of pressure in the film, produced and maintained by the motion of the journal, that explains its existence. The theory also definitely indicates the greatest load which the journal will carry at a given speed without rupturing this oil film. "As the ratio of the load to velocity increases, J I or c increases, and the point H approaches G, when c reaches the value 0·5, which makes $G H = a (1 - c) = 0{\cdot}5\ a$, the pressure of the oil in the film is everywhere greater than at A and B, the pressure in the bath, but for a further increase in the load the pressure falls near A on the *off* side, the fall will cause the pressure to become less than that of the atmosphere, or if sufficient, to become absolutely

* "On" and "off" are used by Professor Reynolds to denote respectively the sides of approach B and of recession A in *Fig.* 1, the arrow indicating the direction of motion. In the paper, the angles θ are reckoned from J O each way; + to right; — to left.

negative, until discontinuity or rupture of the film occurs. The film will then only extend between brass and journal over a portion of the whole arc, and a smaller portion as the load increases or velocity diminishes, *i. e.*, as c increases. Thus, since the amount of negative pressure which the oil will bear depends on circumstances which are uncertain, the limit of the safe load for complete lubrication is that which causes the least separating distance to be half the difference in radii of the brass and journal.

"The rupture of the oil does not take place at the point of nearest approach, but on the *off* side of this, and will only extend up to a point P_2 definitely shown in this theory, which is at the same distance on the *off* side of H as P_1 is on the *on* side. Hence, after this rupture, the brass may still be in equilibrium, entirely separated from the journal, and the question as to whether it will carry a greater load without descending on to the journal will depend on the relative values of

$$\frac{a}{R}$$

and on the smallness of the velocity."

* * * * * * * * *

"This much may be inferred without effecting the integrations for imperfect lubrications; could these be effected, the theory would be as applicable to partial lubrication as it has been to complete lubrication, *i. e.*, a sufficient supply of oil. And as it is, sufficient may be seen to show that with any supply of oil, however insufficient for complete lubrication, the brass will still be completely separated from the journal, although the supporting film of oil will not touch the brass except over a limited area."

* * * * * * * * *

"Another circumstance brought out by this theory, and remarked on both by Lord Rayleigh and the author at Montreal, but not before suspected, is that the point of nearest approach of the journal to the brass is not by any means in the

line of load, and what is still more contrary to common supposition, it is on the *off* side of this line.

"This point H moves as the ratio of load to velocity increases; when this ratio is zero, the point H coincides with O, then as the load increases, it moves away to the left, till it reaches a maximum distance,

$$\frac{\pi}{2} - \varphi_\infty$$

being nearly

$$-\frac{\pi}{2}$$

The load is still small. * * * For further increase of load, H returns towards O, or

$$\frac{\pi}{2} - \varphi_0$$

increases with the largest loads and smallest velocities to which the theory has been applied; this angle is about 40°. With a fairly loaded journal well lubricated, it would thus seem that the point of nearest approach of brass to journal, *i. e.*, the center of wear, would be about the middle of the *off* side of the brass.

"This circumstance, the reason of which is rendered perfectly clear by the conditions of equilibrium, at once explains a singular phenomenon, * * * viz.: that the journal having been run in one direction for some time, and carrying its load without heating, on being reversed, began to heat again, and this after many repetitions always heating on reversal, although eventually this tendency nearly disappeared.

" * * * This is an effect which would necessarily follow in accordance with the theory, so long as there is wear. For the center of wear, being on the *off* side of the line of loads, this wear will tend to preserve or diminish the radius of the brass on the *off* side, and enlarge it on the *on* side, a change which will, if anything, improve the condition for producing oil pressure while running in this direction, but which will

damage the condition on which the production of pressure in the film depends when the journal is reversed and the late *off* side becomes the new *on* side. That with a well-worn surface there should be sufficient wear to produce this result, with * * * slight amounts of using * * * before reversal, seems doubtful; but supposing the brass new, and the surface more or less unequal, the wear for some time would be considerable, even after the initial tendency to heat had disappeared. Hence it is not surprising that the effect should have eventually seemed to disappear."

As regards the frictional resistance of a revolving shaft, the equations (6) and (7) show that it should be directly proportional to the velocity and to the viscosity of the oil, and inversely proportional to the difference of radii of the shaft and bearing. If these two last quantities are constant, the friction will increase directly as the speed, and will be independent of the load. In general, this will not be the case, because both μ and a are themselves functions of both the velocity and the load. Before comparing the results of theory with practice, it is therefore necessary to consider the causes that may cause variations in the values of μ and a. Of these variations, the most important are (1) those due to temperature changes; (2) those due to the pressure in the oil film.

(1) Change in temperature affects—

(*a*) The viscosity of the oil. By a series of experiments on olive oil Reynolds found that between temperatures of 16° and 49° C. the variation in viscosity could be expressed by an exponential law of the form

$$\mu_x = A_0 e - C(t_x - t_0) \qquad (8)$$

where

A_0 = viscosity at temperature t_0 * * * $t_0 = O$

C = coefficient of change for 1° C. * * *

for olive oil

$t_0 = O$.

$A_0 = 3{:}265$ C. G. S. units.

$C = 0{\cdot}0123$.

(*b*) The value of a by reason of difference in coefficient of expansion of the metal of the journal and journal box.

This variation may be expressed in the form

$$a_x = a_0 [1 + E (t_x - t_0)] \qquad (9)$$

E being the ratè at which a increases with temperature. Since E is small (in case of a brass journal box and steel journal 4 inches in diameter, E is about 0·00004), we may put (9) in a form similar to (8), or

$$a_x = a_0 e^{E (t_x - t_0)}$$

(2) Change in pressure affects also the value of a by reason of the elasticity of the material of the journal box. If we take m as the coefficient of this effect, the variation of a with the load, L, may be expressed

$$a_x = a_0 + m L \qquad (10)$$

The total effect on a, due both to rise of temperature $t_x - t_0$ and to load L, will therefore be

$$(a_0 + m l) e^{E (t_x - t_0)}$$

The friction at temperature t_x and load L will be from (6)

$$f = \frac{\mu_0}{a_0 + m L} V e^{-(C + E)(t_x - t_0)} \qquad (11)$$

In any series of experiments, V, the velocity; L, the load; f, the friction actually overcome; and t_0, the temperature of the journal box and shaft, may be measured, and the values of C and μ determined from independent experiments, as already noted. But a_0, m, and particularly t_x, the actual temperature of the oil film, are unknown. Since the oil film is itself the seat of the heating, it is only reasonable to suppose that it will be at least several degrees higher in temperature than the surrounding metal. This rise in temperature is caused by the work spent in overcoming friction, and the heat thus generated has all to be carried away by the oil film (by bodily movement of the oil) or conducted away through the metal surfaces in contact with it. "Consideration of this work and the means of escape gave another equation between the rise of temperature, the friction and the velocity," viz.:

$$f = \left(A + \frac{B}{V}\right)(t_x - t_0) + E\,A\,(t_x - t_0)^2 \qquad (12)$$

where $A + E\,(t_x - t_0)$ represents the rate at which the mechanical equivalent of heat is *carried* away (by the oil) per 1° rise in temperature, B represents the rate at which it is conducted away (by boxes, shaft, etc.).

Comparison of Theory with Experiment.—Professor Reynolds has compared the results of theory with the results of a long series of careful experiments by Mr. Tower, which were undertaken at the instance of the English Institute of Mechanical Engineers.* Although the friction of lubricated surfaces has been the subject of a great deal of experimental investigation by able and careful experimenters, and, "in many cases empirical laws have been propounded; these fail for the most part to agree with each other and with the more general experience." The main cause of this irregularity was found by Mr. Tower to be irregularity in the supply of lubricant. In order to remove this cause as far as possible, he, in one series of experiments, completely immersed the journal box in an oil bath, which was maintained at a definite temperature. "This was very fortunate, for * * * the results so obtained show a great degree of regularity. They show that with perfect lubrication a definite law of the variation of the friction with the pressure and the velocity holds for a particular journal and brass." When Mr. Tower substituted for the bath an oil-pad pressed against the free part of the revolving journal, he also found considerable regularity in the results, but these results were very different from those obtained with the bath. With intermediate lubrication he obtained intermediate results, of which he says: "Indeed, the results, generally speaking, were so uncertain and irregular, that they may be summed up in a few words. The friction depends on the quantity and uniform distribution of the oil, and may be anything between the oil-bath results and seizing, according to the perfection or imperfection of the lubrication."

Of Mr. Tower's experiments, therefore, only those made

* Proc. Inst. Mech. Engineers (English), 1883, 1884.

with the oil-bath can be compared with the results of the theory developed by Professor Reynolds, which has been fully developed, as already pointed out, only for the case of perfect lubrication, *i. e.*, continuous supply of oil at the *on* side of the journal box. In Mr. Tower's experiments, the values of f were measured for various values of V and L, with two boxes, which are designated, respectively, as Nos. 1 and 2. The temperature t_0 measured was that of the oil-bath. The first step in the comparison of the theoretical with the experimental results was to determine t_x, the actual temperature of the oil film. This was done by substituting in equations (11) and (12) the experimental values of f, V, L and t_0, and then determining from these observation equations the value of t_x and of the constants, A, B, E, m and a_0. The test of the theory is in these values being constant throughout the range of experiment.

"It was * * * found that the experiments with the lower loads gave remarkably consistent values for A, B, E, m and a_0, which was also treated as arbitrary. In proceeding to the higher loads for which values of c were greater, the agreement between the calculated and experimental results was not so close, and the divergence increased as c increased. On careful examination, however, it appeared that this discordance would be removed if the experimental frictions were all reduced 20 per cent. This implied that 20 per cent. of the actual friction arose from sources which did not affect the pressure of the film of oil; such a source would be the friction of the ends of the brass against flanges on the shaft, commonly used to keep the brass in its place, or by any irregularity in the longitudinal section of the journal or brass. Although no direct reference is made to such flanges in Mr. Tower's reports, it is such a common custom to neck the shaft to form the journal, that there is great probability of the flanges being used. A coefficient, n, has, therefore, been introduced into the theory, which includes both the effect of necking and of irregularity in longitudinal section. Giving n the value 1.25, the calculated results came into accordance with all Mr. Tower's results for olive oil, the difference being such as

might well be attributed to experimental inaccuracy, and this both as regards the frictions measured with one brass, No. 1, and the distribution of the pressure round the journal with another, No. 2."

"Not only does the theory thus afford an explanation of the very novel phenomena of the pressure in the oil film, but it also shows, what does not appear in the experiments, how the various circumstances under which the experiments have been made affect the results."

"Two circumstances in particular, which are brought out as principal circumstances by the theory, seem to have hitherto entirely escaped notice, even that of Mr. Tower."

"One of these is a, the difference in the radii of the journal and of the brass or bearing. It is well known that the fitting between the journal and its bearing produces a great effect on the carrying power of the journal, but this fitting is supposed to be rather a matter of smoothness of surface than a degree of difference in radii. The radius of the bearing must always be as much larger than that of the journal as is necessary to secure an easy fit, but more than this does not seem to have been suggested."

"It now appears from this theory that if viscosity were constant, the friction would be inversely proportional to the difference in the radii of the bearing and journal, and this, although the arc of contact is less than the semi-circumference; and taking temperature into account, it appears from the comparison of the theoretical frictions with the experiment on brass No. 1, that the difference in the radii at 70° F. was

$$a = 0{\cdot}00077 \text{ (inch)}$$

and comparing the theoretical pressures with those measured with brass No. 2,

$$a = 0{\cdot}00084 \text{ (inch)}$$

or the difference was 9 per cent. greater in the case of brass No. 2."

"These two brasses were probably both bedded to the journal in the same way, and had neither been subjected to any great amount of wear, so that there is nothing surprising in

their being so nearly the same fit. It would be extremely interesting to find how far, under continuous running, prolonged wear tends to preserve this fit. Mr. Tower's experiments afford only slight indication of this. It does appear, however, that the brass expanded with an increase of temperature, and that its radius increases as the load increases in a very definite manner."

The general results of the comparison are finally summed up as follows:

"The experiments to which the theory has been definitely applied may be taken to include all Mr. Tower's experiments with the 4-inch journal and oil-bath, in which the number of revolutions per minute was between 100 and 450, and the nominal loads in pounds per square inch between 100 and 415. The other experiments with the oil-bath were with loads from 415 till the journal seized at 520, 573 or 625, and a set of experiments with brass No. 2, at twenty revolutions per minute. All these experiments were under extreme conditions, for which by the theory c was so great as to render lubrication incomplete, and preclude the application of the theory without further integrations.

"The theory has, therefore, been tested by experiments throughout the extreme range of circumstances to which the particular integrations undertaken are applicable, and the results, which in many cases check one another, are consistent throughout.

"The agreement of the experimental results with the particular equations obtained on the assumption that the brass as well as the journal are truly circular, must be attributed to the same causes as the great regularity presented by the experimental results themselves.

"Fundamental amongst these causes is, as Mr. Tower has pointed out, the perfect supply of lubricant obtained with the oil-bath. But nearly as important must have been the truth with which the brasses were first fitted to the journal, the smallness of the subsequent wear and the variety of the conditions as to magnitude of load, speed and direction of motion.

"That a brass in continuous use should preserve a circular

section with a constant radius requires either that there should be no wear at all, or that the wear at any point P should be proportional to

$$sin\left(\frac{\pi}{2} - P\,J\,H\right)$$

"Experience shows that there is wear in ordinary practice, and even in Mr. Tower's experiments there seems to have been some wear. In these experiments, however, there is every reason to suppose that the wear would have been approximately proportional to

$$c\ sin\,(\varphi_0 - \theta) = c\ sin\left(\frac{\pi}{2} - P\,J\,H\right)$$

because this represents the approach of the brass to the journal within the mean distance a, for all points, except those at which it is negative; at these there would be either no wear at all, or a slight positive wear. So long, then, as the journal ran in one direction only, the wear would tend to preserve the radius and true circular form of that portion of the arc from A to F,* altering the radius at F, and enlarging it from F to B. On reversal, however, A and F change sides, and hence alternate motion in both directions would preserve the radius constant all over the brass.

"The experience emphasized by Mr. Tower, that the journal, after running for some time in one direction, would not run at first in the other, strongly bears out this conclusion. Hence it follows that had the journal been continuously run in one direction, the condition of lubrication, as shown by the distribution of oil pressure round the journal, would have been modified, the pressure falling between O and B on the *on* side of the journal, a conclusion which is borne out by the fact that in the experiments with brass No. 2, which was run for some time continuously in one direction, the pressure measured on the *on* side is somewhat below that calculated on the assumption of circular form, although the agreement is close for the other four points.

"When the surfaces are completely separated by oil, it is

* A point 90° from G in the direction $G\ O\ B$.

difficult to see what can cause wear. But there is generally metallic contact at starting, and hence abrasions, which will introduce metallic particles into the oil (blacken it); these particles will be more or less carried round and round with the journal, causing wear and increasing the number of metallic particles and the viscosity of the oil. Thus the rate of wear would depend on the metallic particles in the oil, the values of,

$$C, \frac{1}{a}$$

and the velocity of the journal, and hence would render the greatest velocity of the journal at which the maximum load with a large value of c could be carried, small—a conclusion which seems to be confirmed by Mr. Tower's experiments with brass No. 2, at twenty revolutions a minute.

"In cases such as engine bearings, the wear causes the radius of curvature of the brass continually to increase, and hence, a and c must continually increase with wear. But, in order to apply the theory to such cases, the change in the direction of the load (or the velocity of approach of the surfaces) would have to be taken into account.

"That the circumstances of Mr. Tower's experiments are not those of ordinary practice, and hence that the particular equations deduced in order to apply the theory definitely to these experiments do not apply to ordinary cases, does not show that the general theory, as given in the general equation, could not be applied to ordinary cases were the conditions sufficiently known.

"These experiments of Mr. Tower have afforded the means of verifying the theory for a particular case, and hence have so far established its truth as applicable to all cases for which the integrations can be effected.

* * * * * * * * *

"The verification of the equations for viscuous fluids under such extreme circumstances affords a severe test of the truth and completeness of the assumptions on which these equations are founded; and the result of the whole research is to

point to a conclusion that not only in cases of intentional lubrication, but whatever hard surfaces under pressure slide over each other without abrasion, they are separated by a film of some foreign matter, whether perceptible or not; and that the question as to whether the action can be continuous or not, turns on whether the motion tends to preserve the foreign matter between the surfaces at the points of pressure, as in the almost if not quite unique case of the revolving journal, or tends to remove it, and sweep it on one side, as is the action of all backward and forward rubbing with continuous pressure.

"The fact that a little grease will enable any surfaces to slide for a time has tended doubtless to obscure the action of the revolving journal to maintain the oil between the surfaces at the point of pressure, and yet, although only now understood, it is this action that has alone rendered machinery or even carriages possible. The only other self-acting system of lubrication is that of reciprocating motion with intermittent pressure and separation of the surfaces to draw the oil back or to draw a fresh supply. This is important in certain machinery, as in the steam engine, and is as fundamental to animal mechanism as is the continuous lubricating action of the journal to mechanical contrivances."

* * * * * * * * *

Measurement of the Thickness of the Oil Film in a Journal Bearing.—Although the remarkable agreement between Professor Reynolds' theory and the results of Mr. Tower's experiments seems to demonstrate conclusively the correctness of the former (as well as the accuracy with which the latter were made), it was thought that it might be interesting to confirm Professor Reynolds' conclusions in an entirely independent manner, *i. e.*, by directly measuring a, the difference in radii between journal box and shaft, under different conditions of load, velocity and temperature. Professor Reynolds considers that there is no method by which this can be directly accomplished; but it occurred to the writer that it might be indirectly done with considerable accuracy by measuring h, the

mean thickness of the oil film. In 1888, I spent considerable time in devising plans by which the problem might be experimentally attacked under actual working conditions. Of the methods which suggested themselves at the time, that which seemed the most promising and practical was to measure the electrical resistance between the box and the shaft when the latter was in motion and at rest. In the latter case the shaft is practically in metallic contact with its box, and the resistance is very low; but in the latter, when it is separated from it by a thin film of oil, the resistance will be raised by an amount depending on the thickness of the film. In order to determine from the measured resistance the thickness of the film, it is necessary to know the specific resistance of the oil and its temperature coefficient, and the temperature and area of the oil film.

It is further necessary to know whether the thickness of the film is uniform, or, if not, in what way it varies.

As regards the general temperature of the oil, t_0, this is easily determined by means of a thermometer placed in a deep cavity in the metal of the box or shaft, as near the bearing surface as possible, the cavity being filled with water, or preferably mercury; or directly in the oil-bath surrounding the shaft, as in Tower's experiments. The mass of the metal surrounding the bearing surfaces is so great in comparison with the mass of the oil, and its conductivity is so high, that the temperature recorded by this thermometer could be but very little lower than the temperature of the oil film itself, which is the seat of the heating. This last can also be directly determined in the manner indicated by Reynolds, from measurements of the friction, f. The area of the film is, of course, the total area of the bearing between box and shaft. The point most difficult to deal with is that of the variation in the thickness of the film over the bearing surfaces. Two distinct causes, which may be classed, respectively, as irregular and regular, tend to introduce differences in thickness between different parts of the oil film. The first includes such irregularities as are due to roughness or inequalities in the surfaces of the box or shaft, or to the introduction of particles of metal

by abrasion, etc. The first cause of irregularity may be avoided by choosing for the experiments a shaft and journal box which have first been carefully fitted to each other, and then allowed to run together (first in one direction, then in the other), a sufficient length of time under light pressure to produce perfectly smooth and polished surfaces; the second by carefully cleaning the box and shaft with benzine before beginning the experiments, and then during the measurements keeping the bearing continually supplied with clean, fresh oil, from a suitable reservoir.

The regular causes of variation in thickness are, first, the differences in pressure in different parts of the journal box. The effect due to differences in pressure can be very nearly eliminated for the purposes of experiment by using two boxes and applying a pressure to the top box, which is equal to the pressure exerted on the box by the weight of the shaft and attached mechanism, or by using, as was done in this case in the experiments which were begun, a Thurston oil-testing machine,* in which the journal brasses are brought together by a spring which acts simultaneously and equally on both top and bottom brasses. A further advantage of using this machine is that the work lost in friction and therefore the heat developed in the box in any given length of time may be conveniently and accurately measured in each experiment. The second cause of variation is that due to eccentricity of the shaft in the box, produced by the variation in the thickness of the film itself. If the bearings are perfectly fitted to each other when they are actually in contact (see *Fig. 2*), then when the two are separated slightly, the opening between the two is greater at the bottom, *a*, than at the edges *b*. In practice, however, the two are more likely to be concentric when slightly separated than when actually together, because that is the condition under which wear between the two takes place. (See Reynolds' remarks, already quoted). Hence, if, as is nearly always the case, the box is softer than the shaft

* For description see Professor Thurston's "Friction and Lost Work in Machinery and Mill Work," John Wiley and Sons, New York; also Pratt & Whitney's Catalogue, 1893 ed., pp. 289-91.

and the two are allowed to run together any length of time at a given pressure equally applied to both boxes, the surfaces will at that pressure be nearly if not quite concentric, particularly if the sides of the box are slightly relieved, as shown in dotted lines in *Fig. 2*, and the direction of motion is frequently reversed.

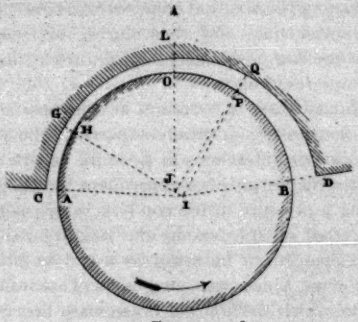


FIG. 2.

In order to carry out this method of measuring the thickness of the oil film, it was first necessary to determine the specific resistance and temperature coefficient of the oil used in the experiments. This was done by the method and with the results recorded in the supplement to this paper. The second part of the investigation, the measurement of the resistance of the film of oil in the journal bearing, had just been begun when the work was interrupted by my departure from the University to accept a Fellowship at Clark University. Since then, I have always hoped to be able to carry the work to completion, but the continued pressure of other duties, as well as the want of appropriate apparatus, has so far prevented me from taking it up again. As I am now permanently engaged upon other entirely different lines of investigation, I have decided to publish the account of the work already completed, in the hope that the results so far obtained may not be uninteresting in themselves, and that some one who has a good oil-testing machine (like the Thurston) and the other

necessary apparatus (a low resistance galvanometer, box of coils, etc.,) at his disposal, may be sufficiently interested in the problem to continue the work along the lines indicated in this paper.

Although the work was interrupted before the complete apparatus for the resistance measurements had been set up and put in working order, some interesting preliminary results had been secured by placing an ordinary (comparatively insensitive) tangent galvanometer directly in series with a resistance box and the revolving shaft, a single gravity cell being used to furnish the current. Qualitative results were thus secured, showing that the resistance was measurably increased even when the pressure was very great and the speed very slow.* The deflection of the galvanometer decreased very rapidly (showing rapid increase of resistance) when the

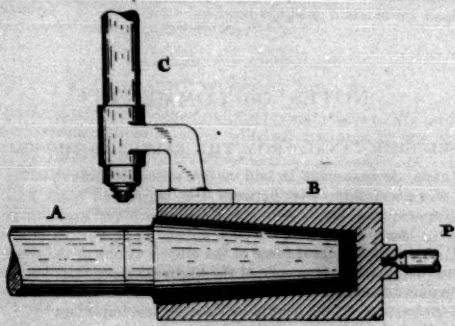


FIG. 3.

speed was raised or the pressure diminished. Under any one condition the deflection was as constant as could have been expected considering the conditions of the experiment, there being at the time no provisions for a constant supply of oil or for the maintenance of constant speed. The method, therefore, seems a promising one.

*This at least confirms Reynolds' conclusion that a film of oil is always present between the moving surfaces.

ADDENDUM.

While writing these notes, another plan of measurement has occurred to me which would be useful as a check on results obtained by the electrical method, although it has not the advantage of the latter in allowing results to be obtained under the same conditions as usually obtain in machine bearings. This would be to have a long conical bearing, *Fig. 3*, accurately fitted to a solid box *B*, whose longitudinal position with respect to the revolving shaft *A* can be accurately located by means of a microscope *C*, mounted on the box and focussed on a fine circumferential line on the shaft. The thickness of the oil film in this case is determined by the longitudinal motion of *B* on *A*. Differing pressures between shaft and box may be produced by a spring or weighted lever acting on the end of the box at *P*.

YERKES' OBSERVATORY, MARCH, 1897.

[*To be concluded.*]

NOTES AND COMMENTS.*

PROPOSED SHIP CANAL FROM THE BALTIC TO THE BLACK SEA.

The Russian government is said to be seriously contemplating the construction of a great ship canal between the Baltic and Black Seas, entirely through Russian territory, to connect the northern and southern portions of the empire. The military value of such a canal in permitting of a concentration of all the available naval force of the empire at one or the other of these points would unquestionably prove of the highest importance; but, in addition to this obvious advantage, it is believed that its value to the agricultural and industrial interests of Russia would be scarcely less important.

We reproduce from the New York *Sun* the following data bearing on the subject:

After a thorough study of the various possible roads, one has been selected as the most practical, running, as it does, entirely through Russian territory. On the plan selected there are no great difficulties of level to be overcome, although the European watershed summit has to be crossed, but this last takes place at one of its lowest points.

The proposed canal's entrance will be on the Gulf of Riga, at the mouth of the River Duna. It will follow the course of this river up to a point above Dunabourg. Then, leaving this valley, it reaches the Berezina River by a straight cut and passes through Babrouisk. This brings it into the Dnieper, and fol-

*From the Secretary's monthly reports.

lowing this natural declivity it reaches the Black Sea, opening into a magnificent roadstead below the Kerson. The total length of this colossal waterway will be something like 1,600 kilometers (about 1,000 miles), and it will be excavated to a depth of 8½ meters (about 27 feet). This will allow the largest iron-clads to navigate it freely from one end to the other. The estimated cost is put down at $500,000,000.

Its strategic importance does not need demonstration. By the selection of a course running at a safe distance from the frontier, it places back of the Russian forces stationed in Poland an unassailable base of operation. Fully protected already by a whole network of fortifications and railways, this canal is intended to act as a feeder for all the war material. As to the concentration of the whole Russian fleet in the Black Sea, this means an absolute control of Constantinople and the Straits.

But if this enterprise is of the utmost importance in a military point of view, it will also prove unquestionably very beneficial to the agricultural and industrial interests of the country. It places vast grain-producing regions in cheap communication with Odessa, the chief point of export, while the immense coal fields of Southern Russia will come into easier connection with the industrial districts of Poland. There are reasons, too, to believe that new factories will develop along the canal on account of the cheapness of this new mode of transport. If this scheme has been adopted, there is no doubt that the Russian tenacity will bring it to success.

TELEGRAPHY WITHOUT WIRES.

The following intelligent summary of the present status of the problem of telegraphy is condensed from a recent editorial utterance of the *Scientific American*, and will be found of interest:

Nikola Tesla has lately announced that he has completed his wireless telegraph to such an extent as to permit of telegraphy through the earth for a distance of twenty miles or more, and his experiments satisfy him of the feasibility of wireless telegraphy on a much more extended scale. In fact, he aims at nothing less than the establishment of a system of telegraphy that shall include the whole earth, and by which items of news may be distributed from one political or commercial center to every other such center throughout the world. This, Mr. Tesla claims, is possible without the interference of one set of signals with another.

He has constructed and tested both transmitting and receiving apparatus, and has found that a surprisingly small expenditure of energy is required. It is impossible, at this writing, to secure details of the apparatus, but it is known that he utilizes the static equilibrium of the earth. This he disturbs at one point, making signals which can be distinguished at one or more distant points.

In his earlier experiments in high frequency currents Mr. Tesla attained a frequency of 10,000 per second; now 2,000,000 oscillations per second is not deemed extraordinary. It is said that the success of the system is assured, but he will not come before the public until every detail is completed. It is understood that the transmission of power from place to place by means of a similar system is contemplated.

While Mr. Tesla has been wrestling with this great problem in this country, Mr. Marconi, a young Anglo-Italian, has been working on the same line in England under the direction of Mr. Preece. It is reported that Mr. Preece has succeeded in telegraphing with certainty and sufficient rapidity from Penarth to Weston-super-Mare, a distance across the water of seven or eight miles, without wires, and it is believed that this distance can be greatly extended.

It is said by *The Engineer* that the apparatus devised by Marconi is extremely ingenious, and has for its object the getting out of the Hertzian vibrations sufficient work for telegraphic purposes. The apparatus comprises a transmitter and receiver. The former consists mainly of a small Ruhmkorff induction coil excited by a couple of battery cells. The secondary or high tension wires terminate each in a metallic ball. Between the two balls is placed a cubical box containing oil. In the opposite sides of the box are fixed two brass balls, oil-tight, so that one-half of each ball is in the oil in the box and the other half outside of the box. The balls do not touch. The whole arrangement has been designed by an Italian professor, Righi. On sending a a current through the induction coil, Hertzian vibrations are set up in the balls and communicated to the ether. The oil has a peculiar effect, acting as a species of brake, the rapidity of the wave vibrations being only about one-half of that stated by Dr. Lodge. These vibrations are then given off into space all around in every direction. So far as known, nothing save metals appears to be opaque to them, and here, therefore, we have an analogy with the Röentgen ray.

Marconi's receiver consists of a tube about ¼ inch in diameter and 3 inches long, in which are two silver plugs terminating in wires, the ends of which are soldered to the silver plugs. The wires are fused into the glass. The tube is exhausted to a near approach to absolute vacuum. The faces of the two silver plugs are very close to each other, and the space between is filled up with an impalpable metallic dust. On the nature of this dust much depends. It must suffice to say that there are in it three constituents, one of which is nickel. Under ordinary conditions this powder will not conduct electricity, save feebly. Its resistance is very high. If a Hertzian ray falls on the little tube, the dust is polarized like the filings in a Hughes test tube, and the powder becomes a conductor. It will be seen at once that we have here a make and break which can be acted on from a distance, and an ordinary Morse sounder does the rest. But matters, after all, are not quite so simple. It is easy to dispatch into space Hertzian waves at intervals corresponding to dots and dashes, but the powder in the receiver, once polarized, remains polarized. To get over this obstacle, a tiny hammer is so arranged that, the moment a current passes through the tube, the hammer taps the side of the tube and depolarizes the powder ready for the next signal.

There is nothing in common between ethereal or wireless telegraphy and telegraphy by induction; the phenomena are wholly distinct. The Hertzian radiance is akin to light, and the polarization of the powder in the receiver finds its analogue in the molecular change which is wrought by light in a sensitized plate.

THE EXPORTATION OF AMERICAN TIN PLATES.

The *Iron Age* is our authority for the interesting statement that the American Tin Plate Company, of Elwood, Ind., has begun the shipment of tin plate to Europe, on regular orders, the first carload of 500 boxes (first quality) having been shipped on an Italian order, on August 11th. A similar order, we are informed by the same authority, is being filled for England.

The *Iron Age* makes some suggestive comments on the facts above named, which are sufficiently interesting to print.

"A few months since, the *Iron Age* printed a brief item crediting one of the largest metal merchants in the country with the statement that we would be exporters of tin plate in two years. The gentleman in question had exceptional opportunities for observation. But to the great majority in the trade the movement is most surprising, as tin plate is one of the few iron and steel products in the manufacture of which the American works were supposed to be still feeling to some extent the competition of foreign brands. The appearance of American tin plate in England will make the cup of bitterness more unpalatable than ever, which is now being held to the lips of the Welsh tin plate manufacturers.

"The progress which is thus shown to have been made in the American tin plate trade is almost beyond belief. Prior to 1890 no tin plate was made here, and the prospects for the establishment of a tin plate industry seemed very remote. After the enactment of the McKinley tariff a few small plants were started, but the business began in a discouragingly slow way. Many who had been ardent advocates of a high tin plate duty, in the belief that capital and skill were impatiently waiting to rush in as soon as the proper encouragement was afforded, were dismayed at the apparent apathy of the sheet manufacturers who had been expected to build tin plate factories as adjuncts to their mills. It was not until 1892 that the industry may be said to have really made a good start, and it was then seen that the builders of the new business would be largely men who had not been prominent in the sheet trade, and in notable instances not even connected with the iron trade. It may be claimed that in the comparatively short period of five years this country has not only built up a tin plate industry great enough to meet its own requirements, but of such strength as to appear tentatively in the markets of the world. The announcement of such an achievement must be gall and wormwood to those who persistently asserted, as late as 1894, that there were no tin plate factories in this country, and never would be.

"It is eminently fitting that the beginning of an export tin plate trade should be made by a company named the American Tin Plate Company. Wherever the products of that company may go they will constitute a proclamation of their origin in themselves.

"We have many euphonious names in the tin plate trade, and many exceedingly attractive names have been adopted to designate the various brands; but of all the list, none could so happily form pioneers in the foreign trade."

HIS SECRET DIED WITH HIM.

"In the death of Mr. Herbert E. Fowler, which occurred recently at Naugatuck, Conn., the secret of electrically depositing copper upon wood or

other rigid or semi-rigid substance is said to have been lost. This process was made possible by coating the substance which was to be plated with copper with a liquid preparation, the secret of which was known only to Mr. Fowler. Every means had been used to induce him to patent the invention, but he declined to do so, fearing that he might lose the value of it in some way. The invention, it is stated, gave much promise of commercial value."

The foregoing statement is clipped from the pages of one of our leading electrical journals. It is a charitable presumption that the item was filled in as padding in response to the compositor's demand for copy. On no other supposition could so erroneous a statement be excused. The art of electro-plating on wood, plaster compositions, and even on textile fabrics, is thoroughly well known to the trade, and is very widely practiced. W.

LONG-DISTANCE TELEPHONY AND THE RAILROADS.

The *Electrical Engineer* has the following of general interest:

"It does not seem within the scope of the ordinary human understanding, says the *Cincinnati Enquirer*, that the immense passenger traffic of a railroad of the marvellous extent of the Pennsylvania Company, or any similar line, could be visibly affected by the long-distance telephone. Such a statement ordinarily would be received with ridicule and laughter by the common railroad officials, and treated with contempt by the higher authorities. Yet, no lesser personage than James McCrea the head of the Western branches of the Pennsylvania system, told President M. E. Ingalls, of the Big Four and Chesapeake & Ohio Railroads, this week, that the business of the famous limited train of their company had been practically ruined by this instrument. These two gentlemen met yesterday in consultation in reference to commercial relations between the two lines, and during their negotiations the subject of the falling off of the passenger traffic of the country was brought up. Various reasons were given, when Mr. McCrea made his decidedly sensational statement. It is well known that the Pennsylvania Limited was originated and run in a measure for the benefit of the brokers and business men of Chicago and the Northwest, who needed quick action in the matter of travel. The trips to New York were taken upon occasions of utmost importance, when time meant thousands of dollars. By means of the Limited the broker or business man was taken to New York in the quickest possible way. There was no delay in getting there; it meant rapid business talk, and equally as quick a return to Chicago. The business man was willing to pay the price assessed for the development in rapid transit displayed by the Limited.

"Then came the introduction of the long-distance telephone. People were slow in realizing its benefit. Slowly but surely they have, however, acquired its significance. A broker in Chicago or a grain dealer in that city has an idea for a big deal; he telegraphs to New York asking for certain information: 'Call me up by long-distance telephone and give me your answer.' The result is that for $15, perhaps $20, a talk is held with the New York man. He has had an opportunity to concentrate his expressions to the shortest possible statement; he has even jotted it down, and at the proper time calls up his man and transacts business. So it is done every day. Mr. McCrea gave as an evidence that in the past he found it necessary to spend

twenty days in the month on the road, leaving but ten days of his time at home. By aid of the long-distance telephone now he has reversed matters; it requires but ten days of his time upon the road, giving him twenty days at home. The matter, when it came to the attention of an *Enquirer* representative, was presented to various business men upon the Chamber of Commerce and upon Third Street. Half a dozen grain men, who have been in the habit of making two and three trips a week to Chicago, said: 'Oh, yes, that has been the case with me; I have, for $3 or $4, been able to transact business which otherwise meant a trip to Chicago or St. Louis.' The same way with commission dealers and brokers. They indorsed the statements of the grain men, and stated that the telephone had saved them numerous trips. The financial brokers and bankers of Third Street use the telephone continually now; in fact, it is quite the feature of several of the more prominent brokers since they have their long-distance telephone connections, but it has never become so prominent a factor in railway circles as has been stamped by Mr. McCrea's utterances. If it practically interferes with a great train like the Limited, a revolution is certainly taking place in railroad affairs."

THE MULHOUSE INDUSTRIAL SOCIETY'S PRIZES.

The Société Industrielle de Mulhouse gives two principal prizes of 5,000 francs each, at intervals of ten years, for discoveries or inventions held to be most usful to Alsatian industries. The next award of one of these prizes will be made in 1899. Other prizes, principally medals, are annually awarded for less important advances in the industrial arts, while money prizes are awarded to workmen, with a view to encouraging the growth of economy and the family affections among them. Among the next awards of interest to engineers is a medal and 500 francs for the best memoir on a new and advantageous method of constructing factory buildings. A medal is offered for a boiler, giving an efficiency of 80 per cent., capable of being worked efficiently at varying outputs, and to cost for maintenance not more than elephant boilers of the same power. Another medal is offered for a satisfactory integrating indicator. Similar awards are offered for new and reliable methods of steam heating, and for large gas engines, while medals and money prizes of 500 francs each are offered for a research on the flow of steam in pipes and for a self-registering pyrometer.

BOOK NOTICES.

Engineering Contracts and Specifications, including a brief synopsis of the law of contracts, and illustrative examples of the general and technical clauses of various kinds of engineering specifications. Designed for the use of students, engineers and contractors. By J. B. Johnson, C.E., Professor of Civil Engineering, Washington University, St. Louis, Mo.; member of the Institution of Civil Engineers; member of the American Society of Civil Engineers; member of the American Society of Mechanical Engineers, etc. Engineering News Publishing Company, New York. Price, $4.00.

Schools of engineering are frequently, perhaps justly, charged with failure to provide their students with a working knowledge of the practical side of the engineering profession.

In this volume Prof. Johnson has taken a notable step toward lifting this reproach. In furnishing an admirable and much-needed discussion of the matters embraced in the title, he has performed a valuable service, not only to the students, but to the practising engineer.

It is, perhaps, a matter of congratulation, that, as stated in the preface, "the author makes no pretension to a knowledge of the law;" for, in law, as in other matters, it is apt to be the layman who can best appreciate his fellow-laymen's difficulties, and who can best decide and supply what they require. While the reader is referred to his attorney, or to treatises on law, for advice and information in important cases, the author, who "has attended lectures in this field in the St. Louis Law School (a department of Washington University)," appears to have succeeded admirably in giving an outline of those legal *principles* with which every engineer should be familiar.

The sample specifications, which usually make up a large portion of such works, are well chosen from the modern practice of noted American engineers, and carefully edited; but the chief merit of the work is in its very thoughtful discussion of the engineering and legal principles underlying the many general and specific clauses of which specifications are necessarily made up.

The work bears, throughout, the impress of careful, intelligent and conscientious labor, and those who have occasion to prepare specifications for important work cannot afford to be without it. J. C. T.

A Text-book of the Principles of Physics. By Alfred Daniell, M.A., etc. (Third Edition). New York: Macmillan & Co. John Wanamaker, Philadelphia.

Daniell's work is one of the few treatises on physics which have received general recognition as standard text-books in English.

The edition above named is the latest, and it will be found to contain an exposition of the principles of the science, in the light of the most recent advances made therein. W.

Franklin Institute.

[*Proceedings of the stated meeting held Wednesday, November 17, 1897.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, November 17, 1897.

MR. JOHN BIRKINBINE, President, in the chair.

Present, 102 members and visitors.

Additions to membership since last report, 25.

The President made some remarks on the approaching completion of the work of stacking the library in the newly arranged fire-proof quarters that have been prepared for the purpose, and urged upon the members the desirability of bringing the change to the notice of their friends.

Mr. Chauncey N. Dutton, of New York, was introduced by the President as the first speaker of the evening. Mr. Dutton gave a description, illustrated with the aid of a working model and numerous detail drawings, of a pneumatic lock for canals, involving a system and apparatus of his invention.

The remarks of the speaker were devoted specially to a lock of this character (62½ feet lift) which he had designed for Lockport, New York, and which had been approved by the Canal Commissioners of the State of New York. The subject evoked a lengthy discussion, participated in by Messrs. E. A. Scott, Spencer Fullerton, G. M. Eldridge, Joseph Richards, Theo. D. Rand, the President and Mr. Dutton.

On Mr. Fullerton's motion, duly seconded, the subject of the paper was referred to the Committee on Science and the Arts for investigation and report.

Mr. Wm. C. Henderson, by invitation, presented a communication "On Kryolith, its Mining, Preparation and Utilization." The communication was illustrated with the aid of a series of lantern slides.

The Secretary called attention to a method of determining the density of smoke from furnace chimneys, devised by Dr. Ringelman, and illustrated the system with the aid of a lantern slide.

Adjourned.

WM. H. WAHL, *Secretary.*

COMMITTEE ON SCIENCE AND THE ARTS.

[*Abstract of proceedings of the stated meeting held November 3, 1897.*]

MR. JAMES CHRISTIE in the chair.

Reports on the following subjects passed first reading:

Perpetual Power with Manageable Air-Ship, J. A. Klefler, Philadelphia

The Duplication of the Cube, Charles Morrell, Chicago, Ill.

Investigations with the Electric Furnace, Henri Moissan, Paris, France.

Improvements in Tidal Powers, Ernst Markmann, Philadelphia.

"Franklin Medal" Foundation (Institute).

Reports on the following subjects were adopted :

All-Wrought-Steel Pulley, Thomas Corscaden, Philadelphia. Reserved for publication in full.

Percussion Wheel.—Francis M. F. Cazin, New York.

ABSTRACT.—This invention applies to water-wheels of the percussion type, and the improvements relate to the crown of the wheel, to the water-buckets to be connected in pairs to the said crown, and to the manner of connecting these pairs of buckets with the said wheel crown.

More specifically :

(1) The improvements relate to the peculiar form given to the concavity of each bucket, for the purpose of securing to the water-jet, striking them under head, a regular curved or segmental line of contact in whichever of the possible directions the water may strike them while they recede from the nozzle as the wheel is revolving ; and

(2) To the arrangement of pairs of these buckets to the effect of being in immediate contact with one another as pairs, each of the pairs having the same regular cavity, with no division or interruption by a ridge or projection, and with no difference to distinguish between them as right and left, with no cutting away of either front or side walls, and with no rim or wheel-ring or wedge between them, but provided with a superstructure by which the jet is divided into halves even before it touches the buckets ; all for the purpose of effecting such a division of jet on as sharp an angle as possible.

The report finds that the Cazin improvements do not embrace the principles upon which the wheels known as impact wheels, jet-wheels, etc., operate, but are confined to the construction of the buckets and the application of the jet by which provision is made.

(1) For dividing the jet on a line parallel with the shaft of the wheel, and this first division into another and inner part, this being so precisely regulated that, while the top of each vane causing the first division passes through the jet, the interrupted inner part is guided into the vane and is—

(2) There divided into halves on a line at right angles to the first (top) line of division, and in the central plane of rotation, being then distributed between two bucket cavities, where each half is made to serve the purpose of force transmission by being uninterrupted by and completely immersed in its direction of flow on true curves.

Applicant claims that the form and arrangement of buckets adopted by him are derived from mathematical calculations, and that by their use only can there be accomplished the complete and permanent inversion of flow of force jets. The constructive lines thus developed by the applicant have been made the subject of letters-patent of the United States, No. 578,812, March 16, 1897.

In the absence of data derived from comparative tests of efficiency of the Cazin and other forms of impulse wheels, and in view of the circumstance that circular lines for buckets have long been known and described in treatises on hydraulics as the ideal form to realize a complete inversion of the jet, the sub-committee charged with this investigation fails to find ground for a favorable report. [*Sub-Committee.*—Wm. M. Barr, Chairman ; John E. Codman, Chas. G. Darrach, Henrik V. Loss.]

Balanced Locomotive Driving Wheel.—Philip Z. Davis, Philadelphia.

ABSTRACT.—This applicant claims a system of balancing for the revolving and reciprocating parts of a locomotive driving-wheel, consisting in the use and special disposition of two counter-weights. The arrangement is disclosed in U. S. letters-patent Nos. 578,597–8 and 9, dated March 9, 1897, to which reference is made for details, of which it is difficult to make an intelligible abstract.

The report of the Sub-Committee is unfavorable to the applicant's claims, and concludes with the statement that "the problem of counter-balancing the reciprocating parts of a locomotive and the revolving parts at the same time, is as far from solution as ever." [*Sub-Committee.*—Wilfred Lewis, Chairman; Henry F. Colvin, Hugo Bilgram, S. M. Vauclain, Wm. P. Evans.]

Combination Book-Shelf and Book-Support.—August Lundberg, Worcester, Mass.

ABSTRACT.—This is a movable book-support to be used on book-shelves to keep a row of books upright when the shelf is not full. It is made of sheet metal, bent at right angles, the one part to stand vertically for the book to rest against, and the other to lie flat upon the shelf, and upon which the weight of the book or books rests. The special difference between the Lundberg invention and others of its class consists in the fact that it does not depend upon the weight of the books to keep the support in the right position to hold the books upright, but has the horizontal arms formed of metal sufficiently thick to allow them to act as tongues to traverse in grooves formed on the face of the shelf, to make the support slide always parallel with the length of the shelf, and to keep the support from being pushed backward or forward by the removal or insertion of books.

The report finds that the Lundberg modification is not a desirable one, for the reasons that it adds both to the cost of constructing the shelves and of the support itself, and would make the shelves more destructive to the books. [*Sub-Committee.*—Henry R. Heyl, Chairman; Spencer Fullerton.]

Pneumatic Pyrometer.—Uehling & Steinbart Co., Ltd., New York.

The object of this invention is to produce an instrument for accurately and continuously indicating high temperatures. The principle involved is the law of the passage of gas or air under a constant forced flow through small apertures. In the provision of a device for effecting this object, its primary feature is the forcing of air or gas through two successive small apertures, whereby the tension between them will remain constant so long as the temperature of the passing fluid remains equal and constant at both apertures, and whereby a change of temperature at either one or the other of the apertures will also cause a change of tension between them. If, therefore, the fluid as it passes through one of these apertures is made to vary with the temperature to be measured, while at the other it is constantly kept at a certain normal temperature, then the variation of the tension between the apertures will be a measure of the degree of heat the air has at the time of entering into the space or conduit between and connecting the two apertures, and hence of the temperature to be measured. For carrying out this operation and obtaining this result, the invention consists of certain novel parts and combinations of parts, for the detailed account of which reference is made to the full text of report, or to U. S. letters-patent granted to Edward A. Uehling and Alfred Steinbart, No. 11,413, April 17, 1894.

The report of the sub-committee finds that the principle on which this pyrometer acts is theoretically correct, and has not heretofore been applied to this purpose, and that the instrument in actual use is very satisfactory. The John Scott award is therefore recommended. [*Sub-Committee.*—H. W. Spangler, John Hartman, A. E. Outerbridge, Jr.]

Holophane Globes.—Geo. A. Macbeth Company, Pittsburgh, Pa.

ABSTRACT.—The object of this invention is to secure diffusion of the light by means of a transparent globe of such construction as to insure that the light usually lost by being sent off into the space above the horizontal plane passing through the source of the light, shall be distributed in the space below that plane and thus be made useful. To effect this result the principles of reflection and refraction are called into service, and the contour of the globe is given a form such that these principles are made available.

The details of the special construction of these globes cannot be intelligently understood without the aid of illustrations, and the reader is accordingly referred to the full text of the report, or to the letters-patent of the United States, No. 563,836, July 14, 1896, granted to the inventors, Messrs. Andrée E. Blondel and Spiridion Psaroudaki, of Paris, France.

The report of the investigating sub committee finds that MM. Blondel and Psaroudaki have invented a globe that secures much better diffusion and more satisfactory distribution of light than any other globe known to the committee; that its manufacture on the commercial scale has been satisfactorily accomplished, and that the invention has made a distinct improvement in the diffusion and distribution of artificial light.

The John Scott award is therefore recommended to the inventors. [*Sub-Committee.*—George A. Hoadley, Chairman; George F. Stradling, George U. G. Holman, Edward A. Partridge, George Strawbridge, Clayton W. Pike.]

SECTIONS.

MINING AND METALLURGICAL SECTION.—Stated meeting November 10, Mr. Benj. Smith Lyman, President, in the chair.

Mr. John Gifford, Princeton, N. J., presented a communication on "Forestry as Related to Geology and Engineering."

Mr. Wm. C. Henderson, Secretary of the Section, read a paper on "Kryolith: its Mining, Preparation and Utilization," illustrated with lantern projections of views of the mining of kryolith at Ivigtut, Greenland, and with specimens of the raw material, and various products manufactured therefrom.

CHEMICAL SECTION.—Stated meeting November 16th, Dr. Lee K. Frankel in the chair.

Dr. Bruno Terne read a paper on "Ammonia and its Sources."

ELECTRICAL SECTION.—Stated meeting November 23d, Mr. Clayton W. Pike, President, in the chair.

Mr. W. E. Harrington read a paper on "Railway Bonding."

Mr. J Lester Woodbridge, of New York, addressed the Section on "The 'Booster' System as Applied to Electric Railways."

[The papers above-named will appear in full in the *Journal* in due course.]